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(54) INTEGRATED CONTROL APPARATUS FOR VEHICLE

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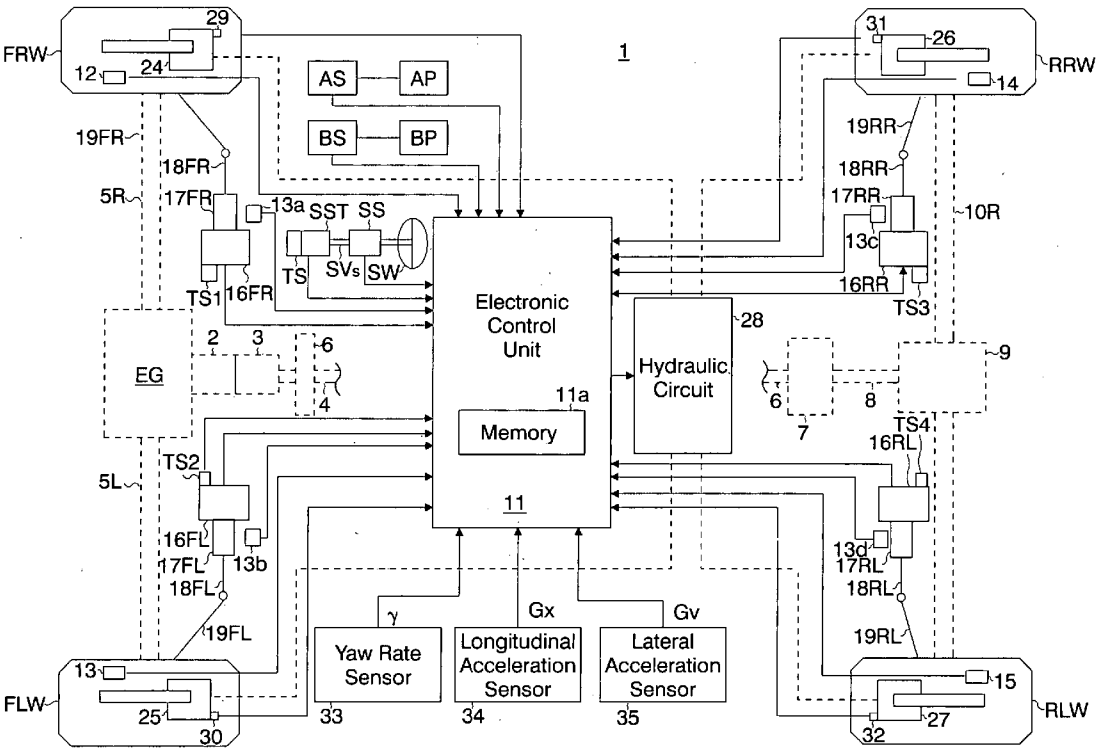
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(57) ABSTRACT

In a vehicle of a four-wheel independent steering type, an electronic control unit calculates a target yaw rate in accordance with a vehicle speed and a steering angle, and calculates a vehicle-control target value on the basis of the target yaw rate and an actual yaw rate. The electronic control unit estimates the grip factors of the individual wheels to road surface, and sets a distribution ratio for distribution of the vehicle-control target value among actuators of a steering system, a brake system, and a drive system in accordance with the estimated grip factors. The electronic control unit controls the actuators of the three systems in accordance with control instruction values determined on the basis of the vehicle-control target value and the distribution ratio.



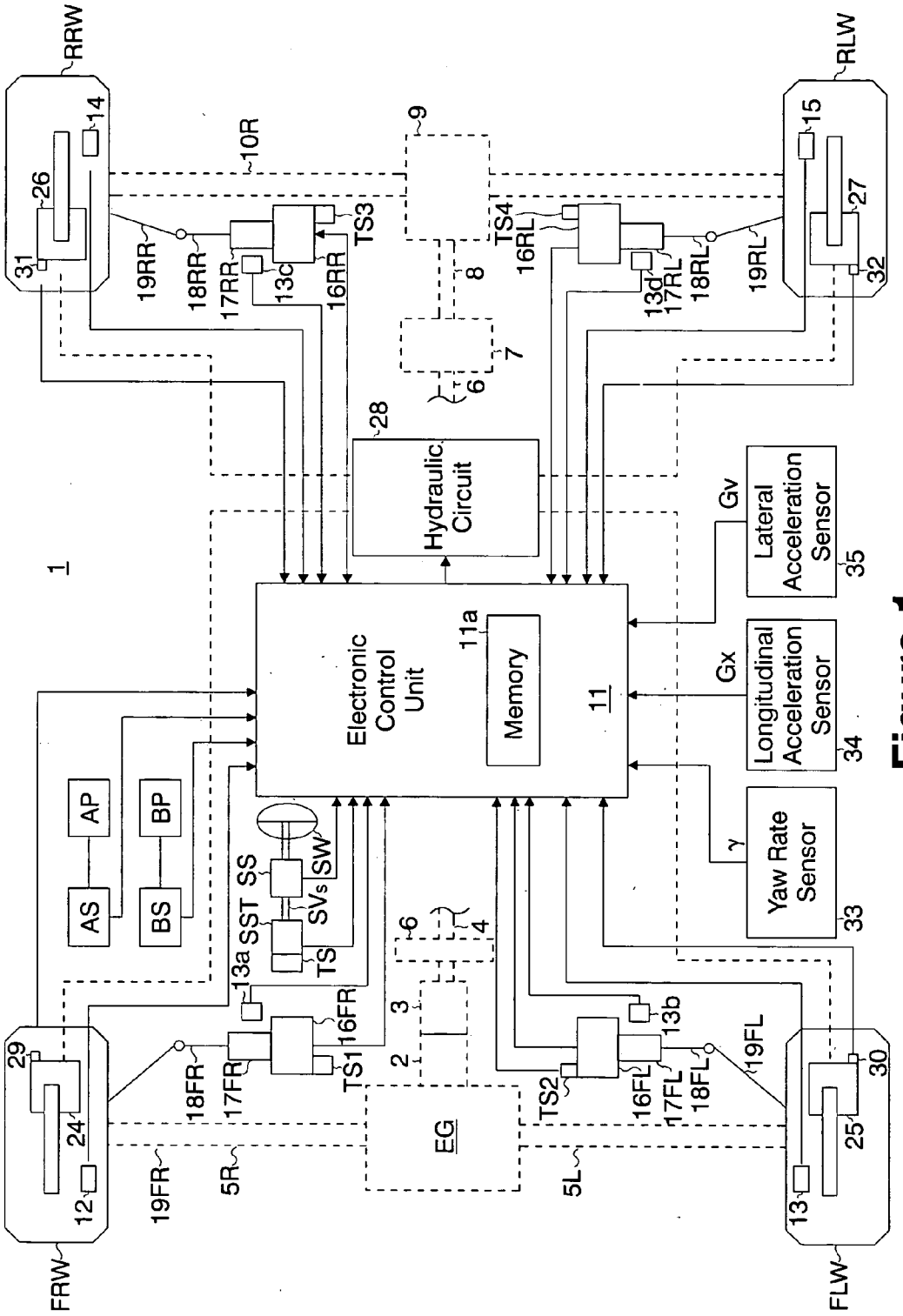

RRW
RLW
FRW
FLW
1
Electronic Control Unit
11
11a
Memory
Hydraulic Circuit
28
Lateral Acceleration Sensor
35
Longitudinal Acceleration Sensor
34
Yaw Rate Sensor
33
Gv
Gx
γ
AP
BP
AS
BS
SST
SS
SVs
SW
TS
TS1
TS2
TS3
TS4
EG
2
3
4
6
7
8
9
10R
5R
5L
12
13
14
15
24
25
26
27
29
30
31
32
13a
13b
13c
13d
16FR
16FL
16RR
16RL
17FR
17FL
17RR
17RL
18FR
18FL
18RR
18RL
19FR
19FL
19RR
19RL

Figure 1

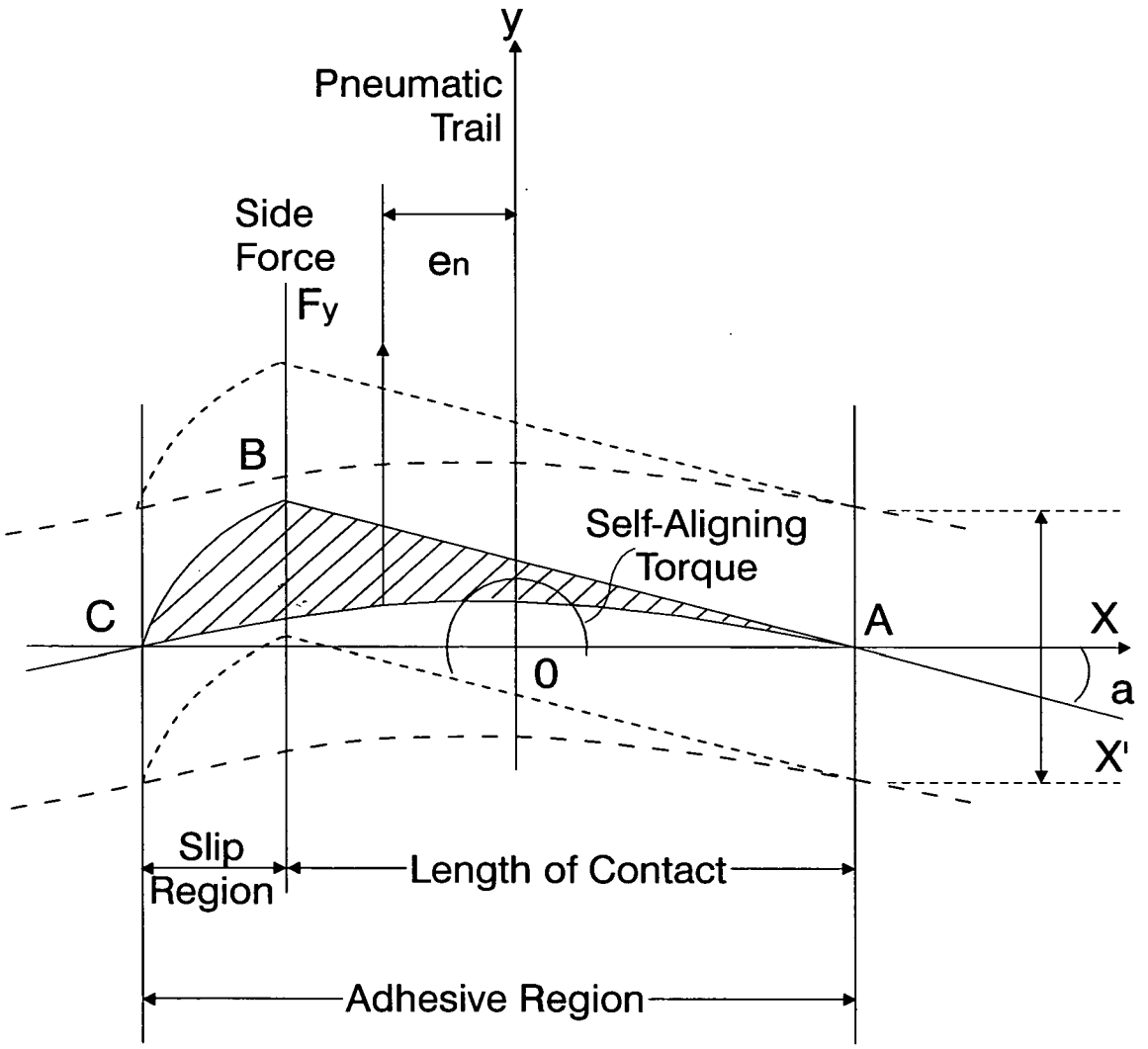

y
Pneumatic
Trail
Side
Force
Fy
en
B
Self-Aligning
Torque
C
A
X
0
a
X'
Slip
Region
Length of Contact
Adhesive Region

Figure 2

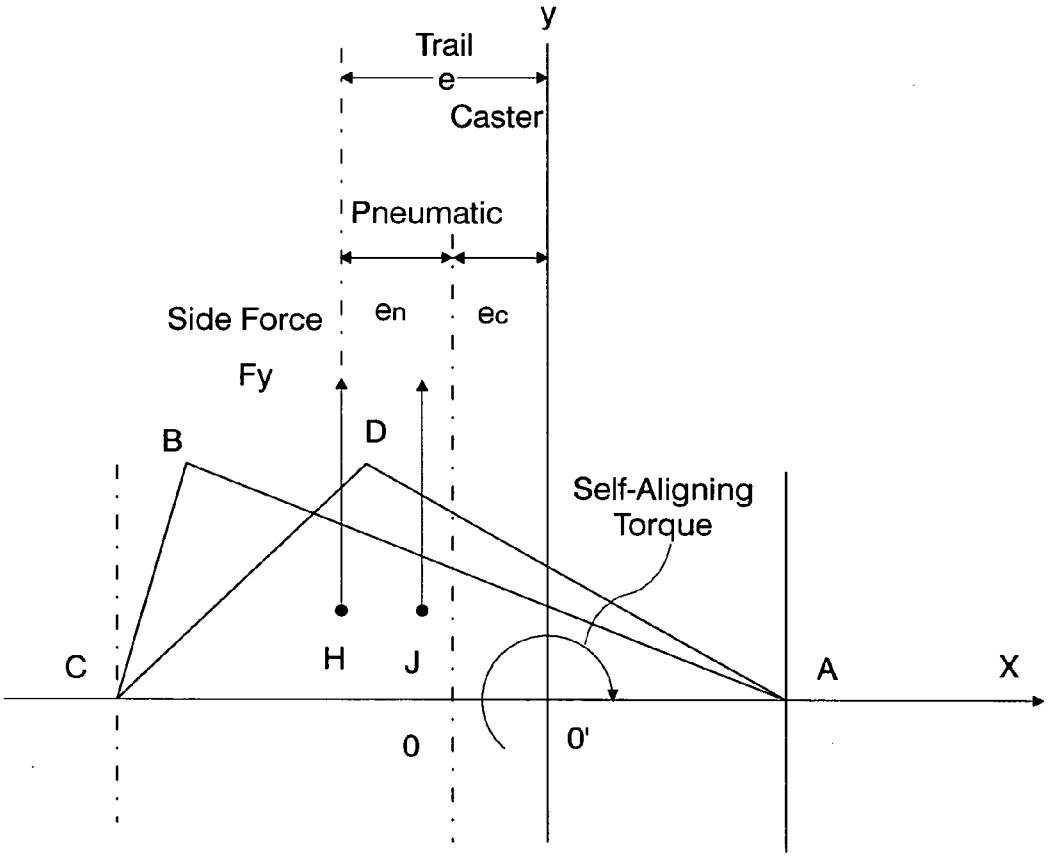

y
Trail
e
Caster
Pneumatic
Side Force
Fy
en
ec
B
D
Self-Aligning
Torque
C
H
J
A
X
0
0'

Figure 3

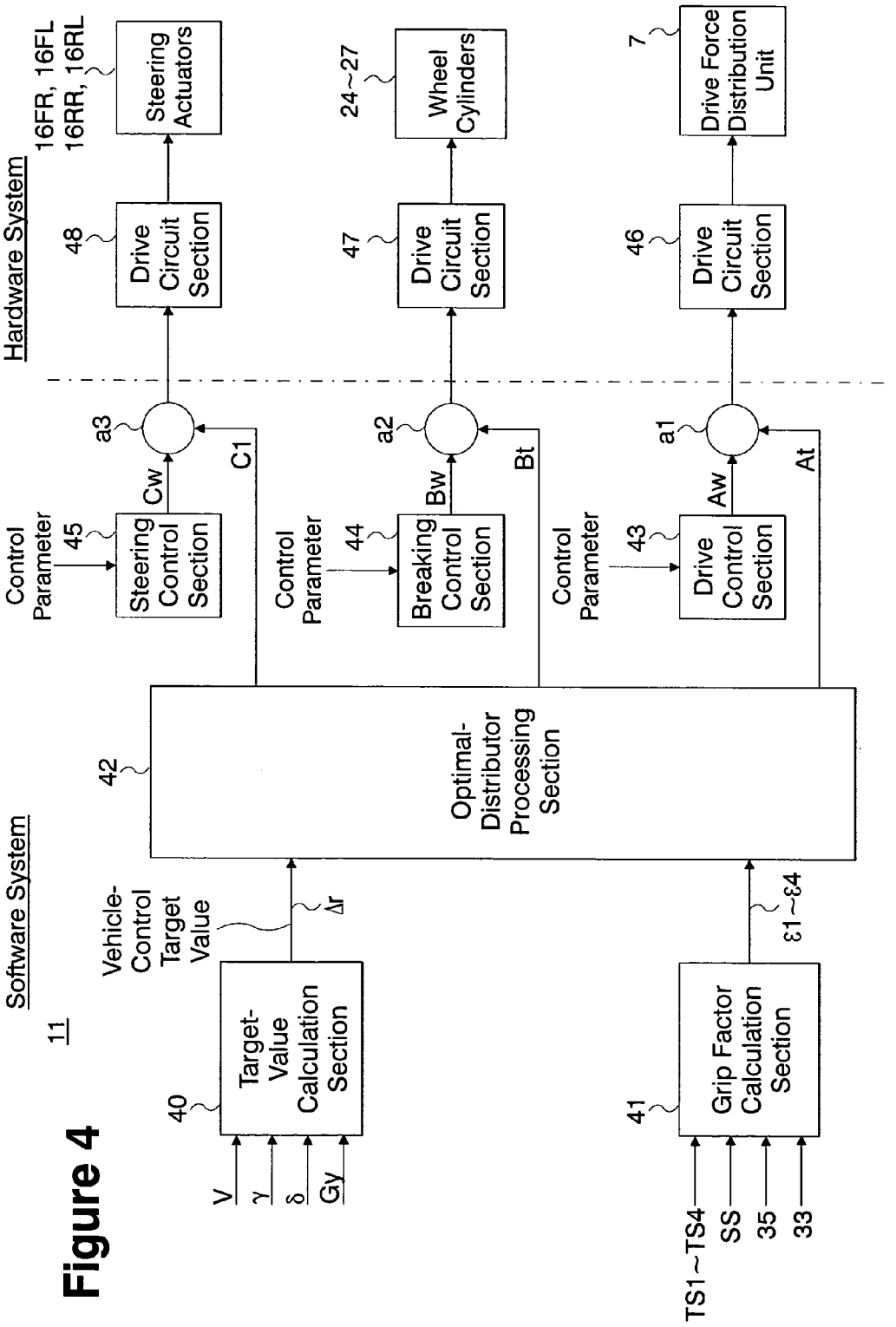

Hardware System
Software System
11
16FR, 16FL
16RR, 16RL
Steering Actuators
24~27
Wheel Cylinders
7
Drive Force Distribution Unit
48
Drive Circuit Section
47
Drive Circuit Section
46
Drive Circuit Section
a3
a2
a1
Cw
Bw
Aw
C1
Bt
At
Control Parameter
45
Steering Control Section
Control Parameter
44
Breaking Control Section
Control Parameter
43
Drive Control Section
42
Optimal-Distributor Processing Section
Vehicle-Control Target Value
Δr
ε1~ε4
40
Target-Value Calculation Section
41
Grip Factor Calculation Section
V
γ
δ
Gy
TS1~TS4
SS
35
33

Figure 4

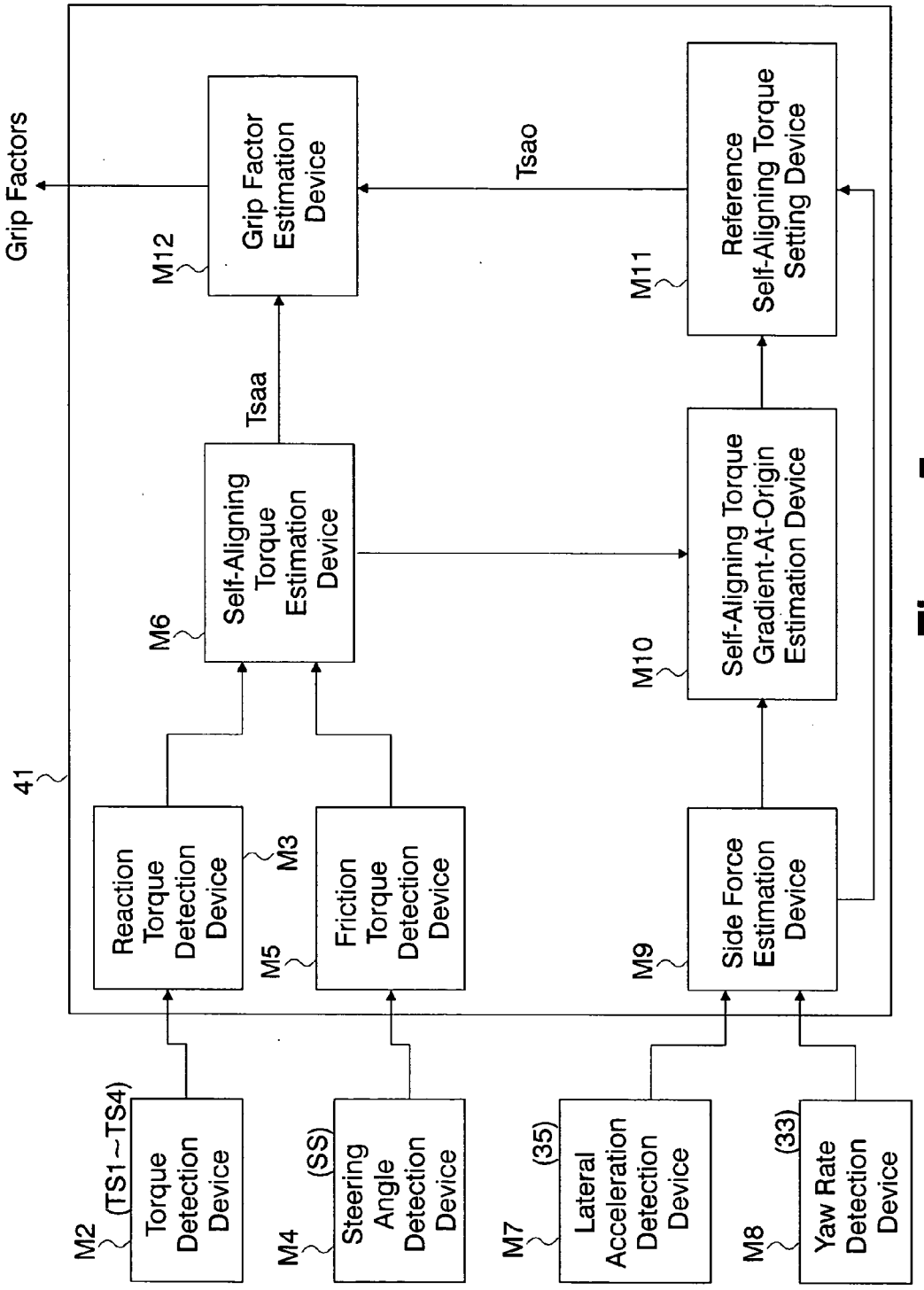
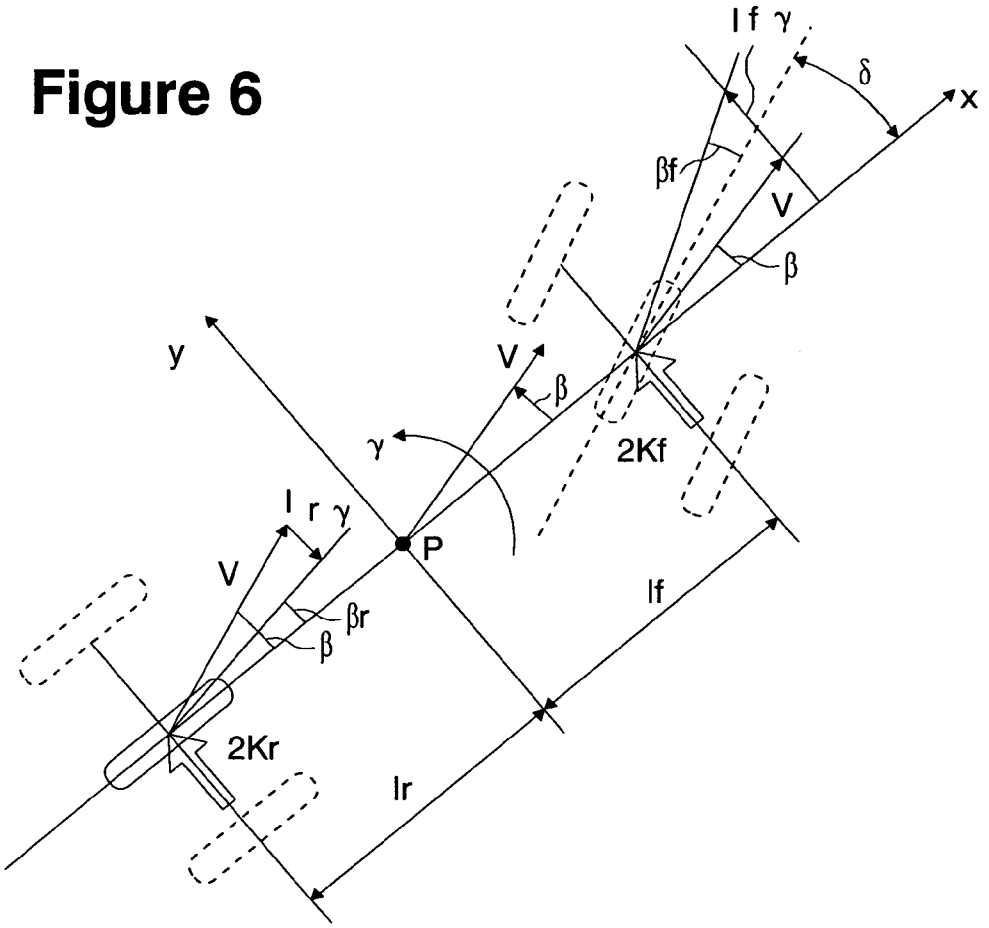

Grip Factors
M12
Grip Factor Estimation Device
Tsao
M11
Reference Self-Aligning Torque Setting Device
Tsaa
M6
Self-Aligning Torque Estimation Device
M10
Self-Aligning Torque Gradient-At-Origin Estimation Device
41
Reaction Torque Detection Device
M3
M5
Friction Torque Detection Device
M9
Side Force Estimation Device
M2
(TS1~TS4)
Torque Detection Device
M4
(SS)
Steering Angle Detection Device
M7
(35)
Lateral Acceleration Detection Device
M8
(33)
Yaw Rate Detection Device

Figure 5

Figure 6



γ	: Actual Yaw Rate
V	: Vehicle Speed
β	: Vehicle-Body Skid Angle
Kf	: Front Cornering Power
Kr	: Rear Cornering Power
lf	: Distance between Front Axle and Center of Gravity of Vehicle
lr	: Distance between Rear Axle and Center of Gravity of Vehicle
δ	: Actual Steering Angle
βf	: Front-Wheel Skid Angle
βr	: Rear-Wheel Skid Angle

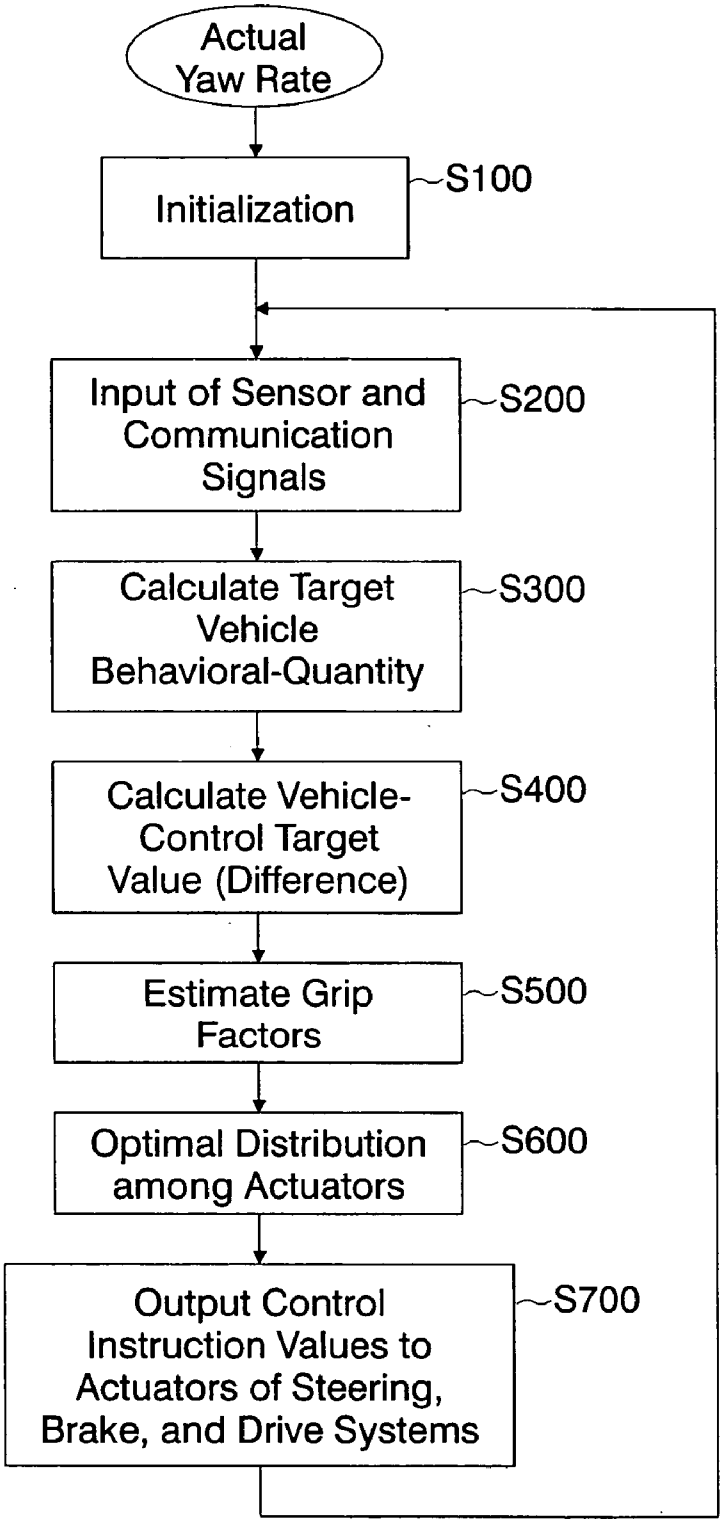

Actual Yaw Rate
Initialization
S100
Input of Sensor and Communication Signals
S200
Calculate Target Vehicle Behavioral-Quantity
S300
Calculate Vehicle-Control Target Value (Difference)
S400
Estimate Grip Factors
S500
Optimal Distribution among Actuators
S600
Output Control Instruction Values to Actuators of Steering, Brake, and Drive Systems
S700

Figure 7

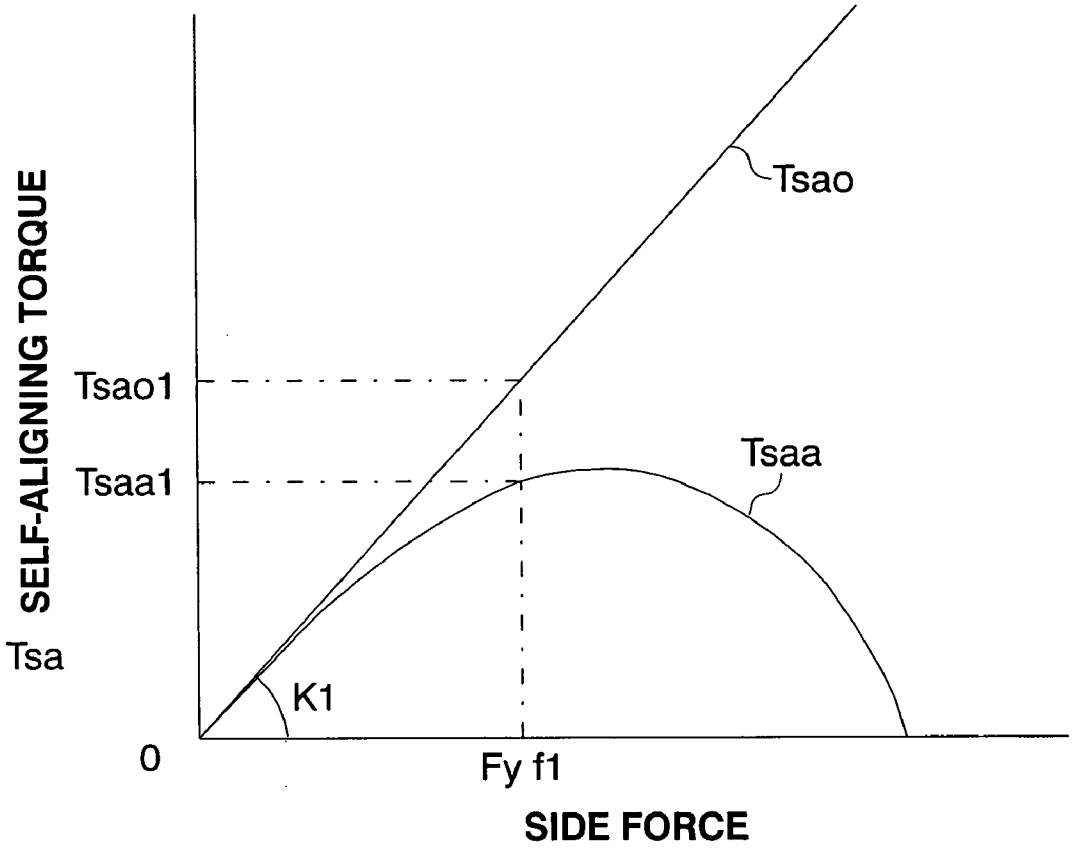

SELF-ALIGNING TORQUE
Tsa
Tsao
Tsao1
Tsaa
Tsaa1
K1
0
Fy f1
SIDE FORCE

Figure 8

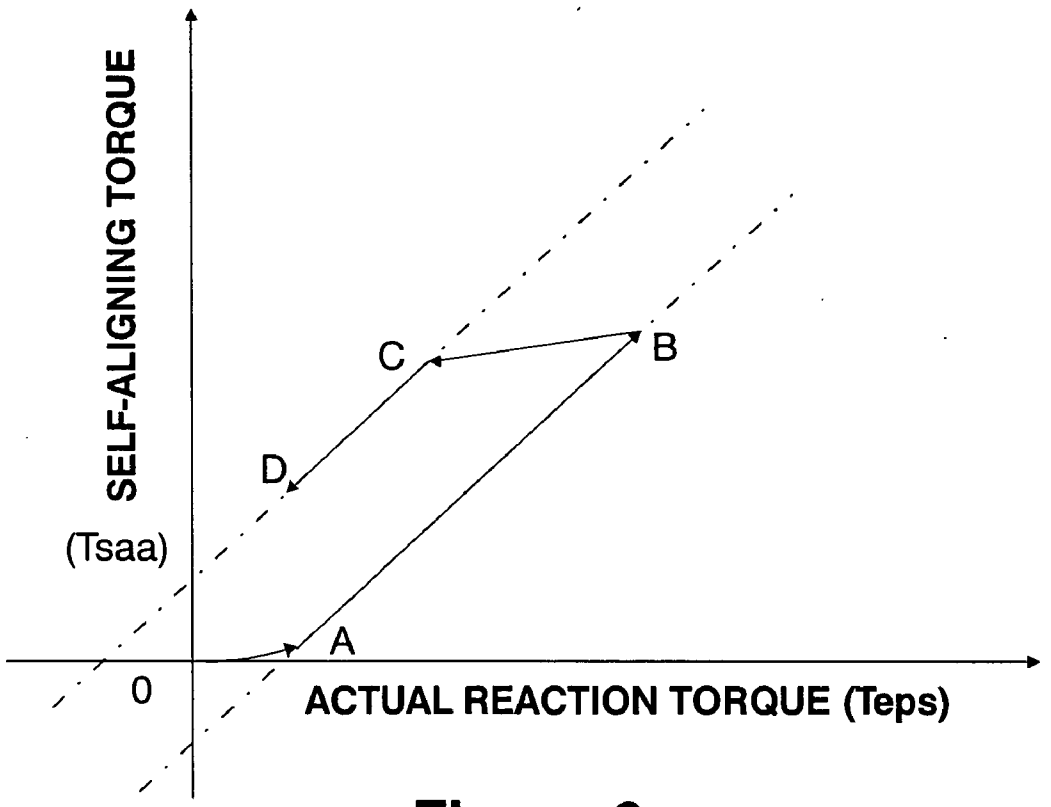

SELF-ALIGNING TORQUE
(Tsaa)
C
B
D
A
0
ACTUAL REACTION TORQUE (Teps)

Figure 9

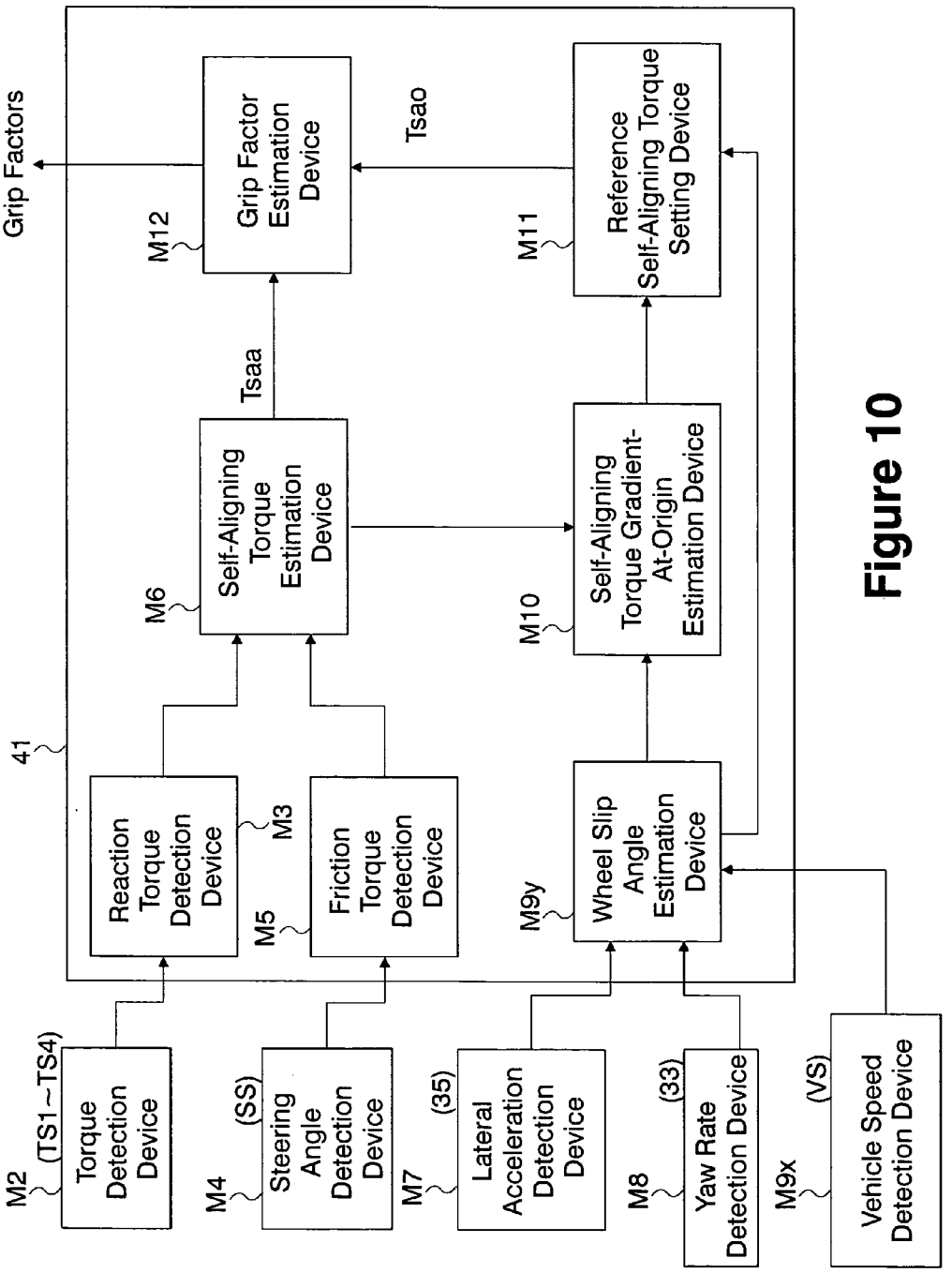

Grip Factors
Grip Factor Estimation Device
M12
Tsao
Reference Self-Aligning Torque Setting Device
M11
Tsaa
Self-Aligning Torque Estimation Device
M6
Self-Aligning Torque Gradient-At-Origin Estimation Device
M10
41
Reaction Torque Detection Device
M3
Friction Torque Detection Device
M5
M9y
Wheel Slip Angle Estimation Device
M2
(TS1~TS4)
Torque Detection Device
M4
(SS)
Steering Angle Detection Device
M7
(35)
Lateral Acceleration Detection Device
M8
(33)
Yaw Rate Detection Device
M9x
(VS)
Vehicle Speed Detection Device

Figure 10

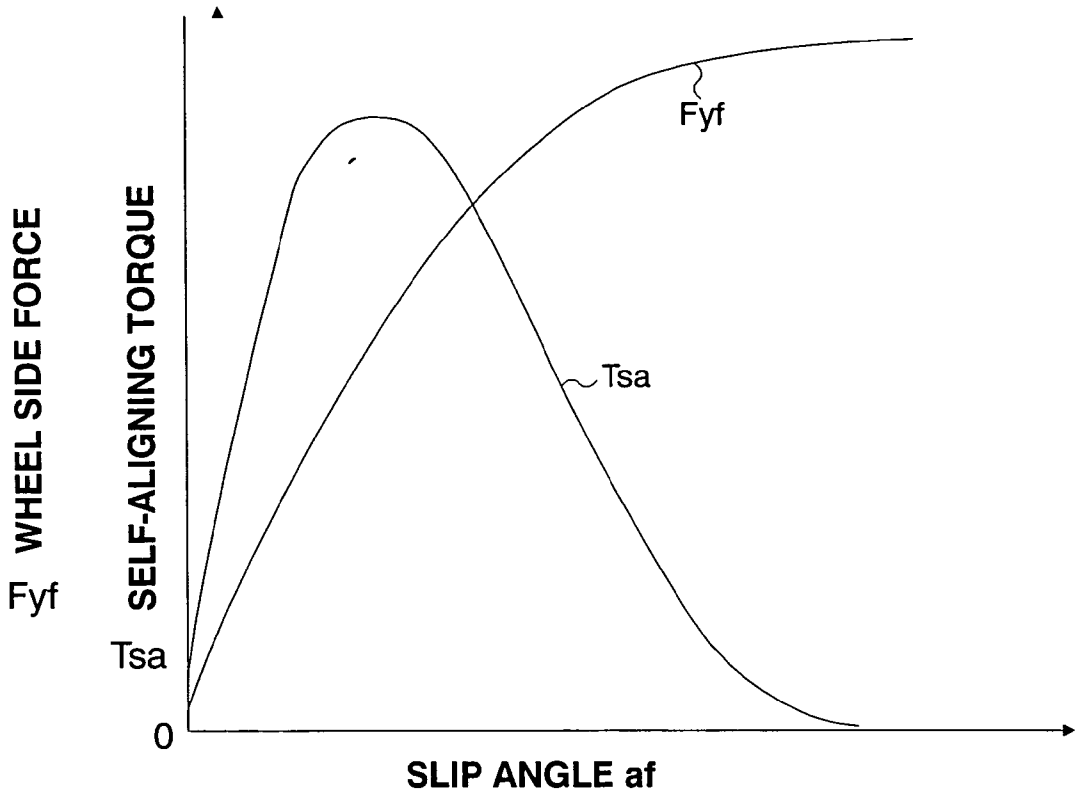

WHEEL SIDE FORCE
Fyf
SELF-ALIGNING TORQUE
Tsa
0
Fyf
Tsa
SLIP ANGLE af

Figure 11

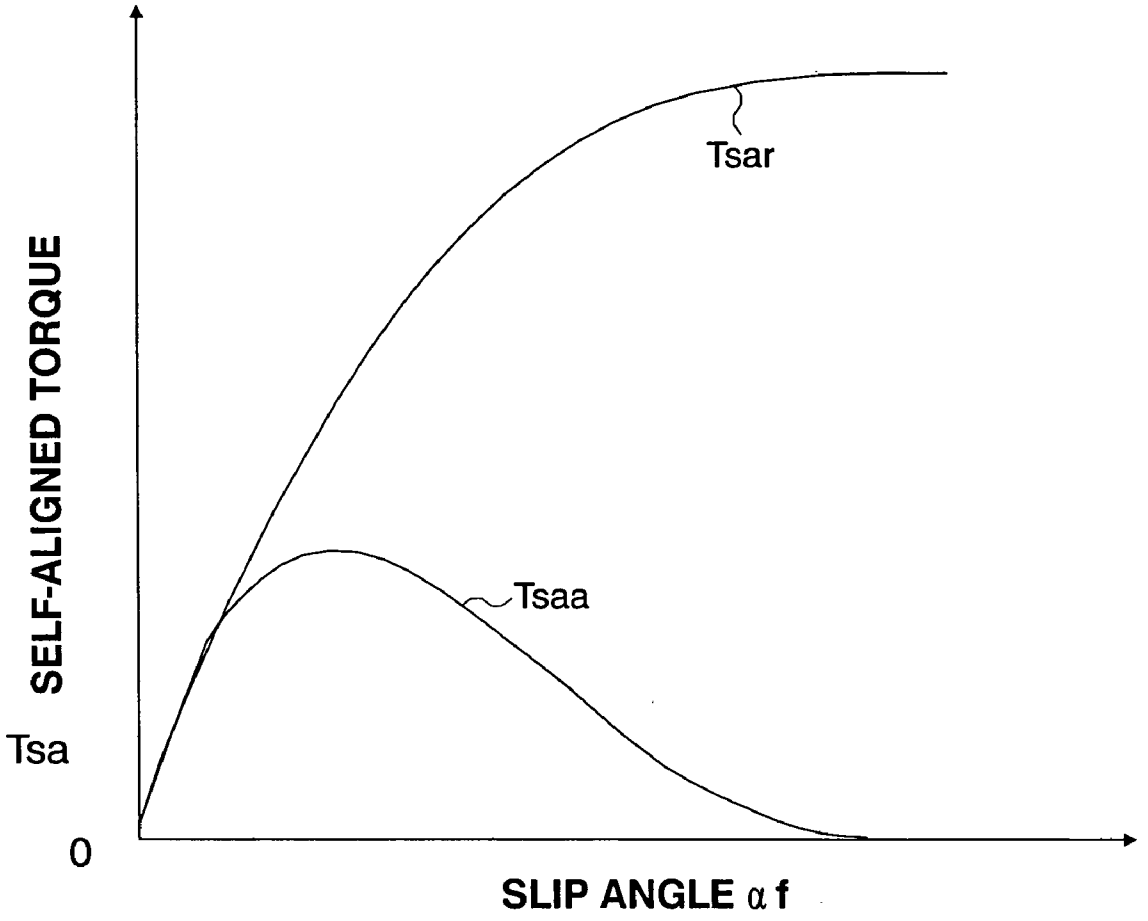


Figure 12

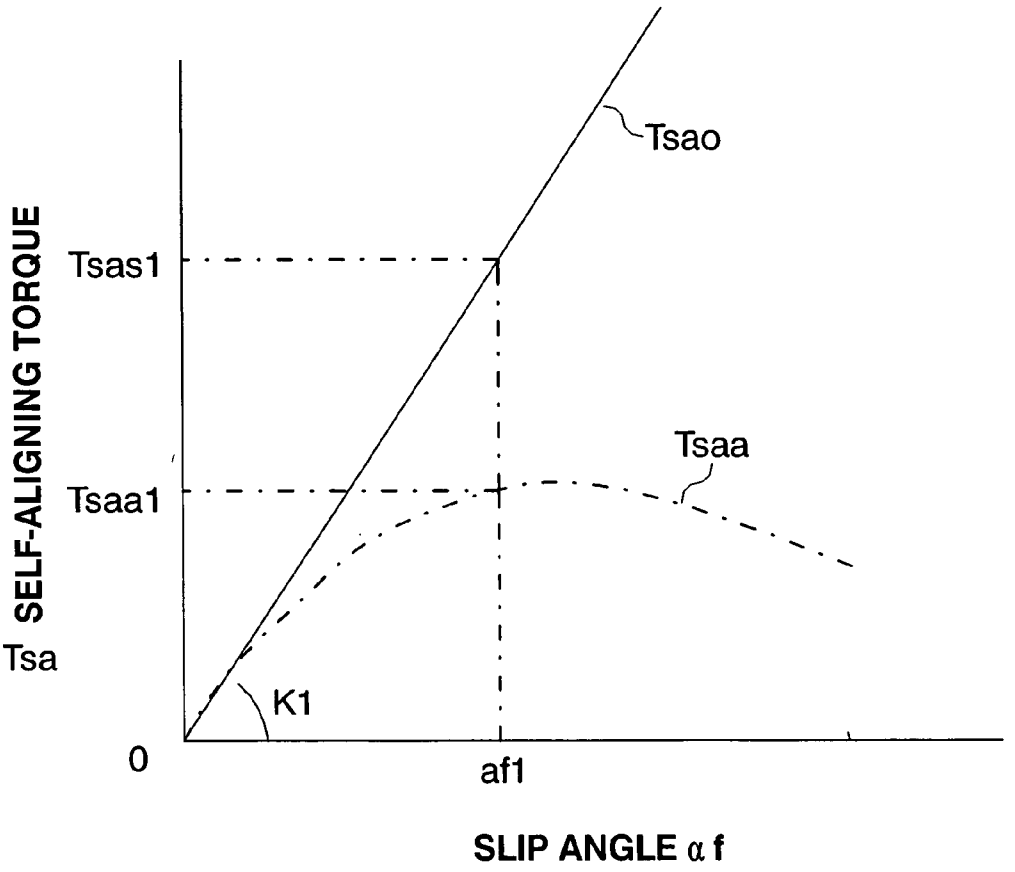

SELF-ALIGNING TORQUE
Tsa
Tsas1
Tsaa1
0
K1
af1
Tsao
Tsaa
SLIP ANGLE α f

Figure 13

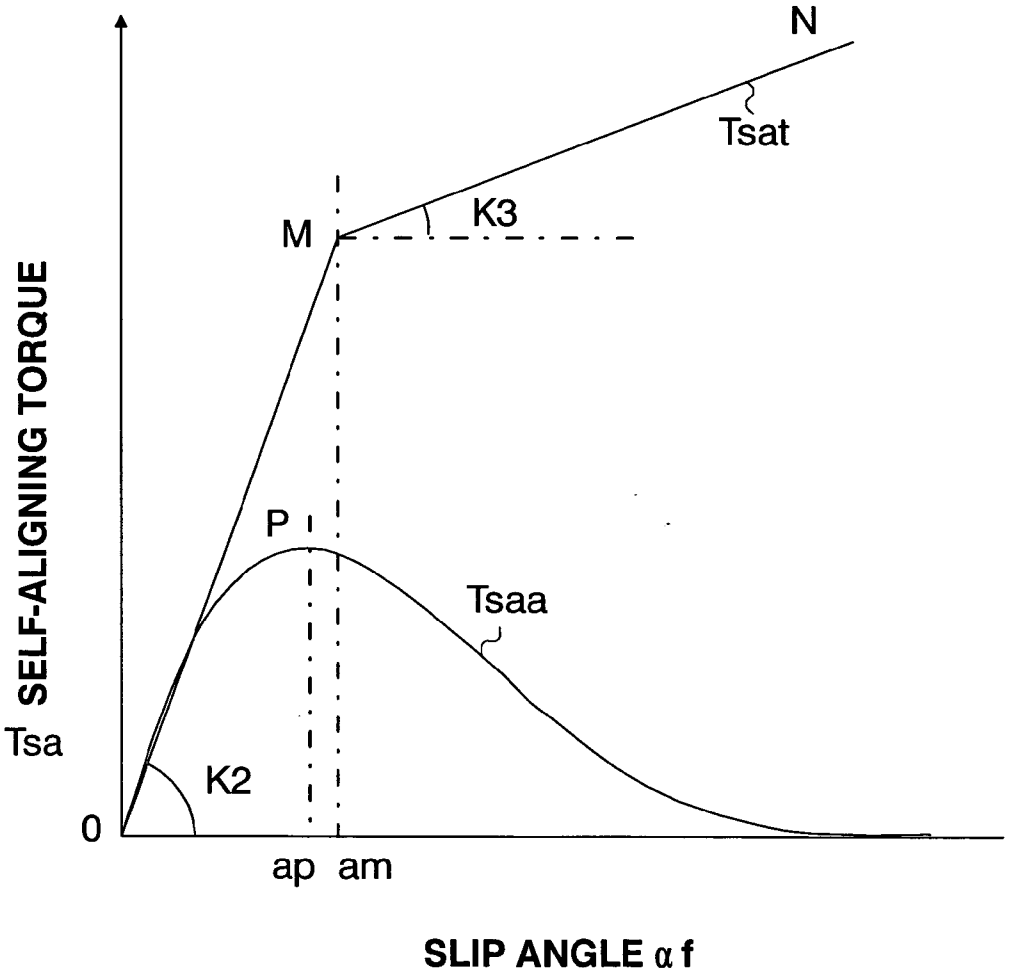

N
Tsat
K3
M
P
Tsaa
K2
0
ap
am
SELF-ALIGNING TORQUE
Tsa
SLIP ANGLE α f

Figure 14

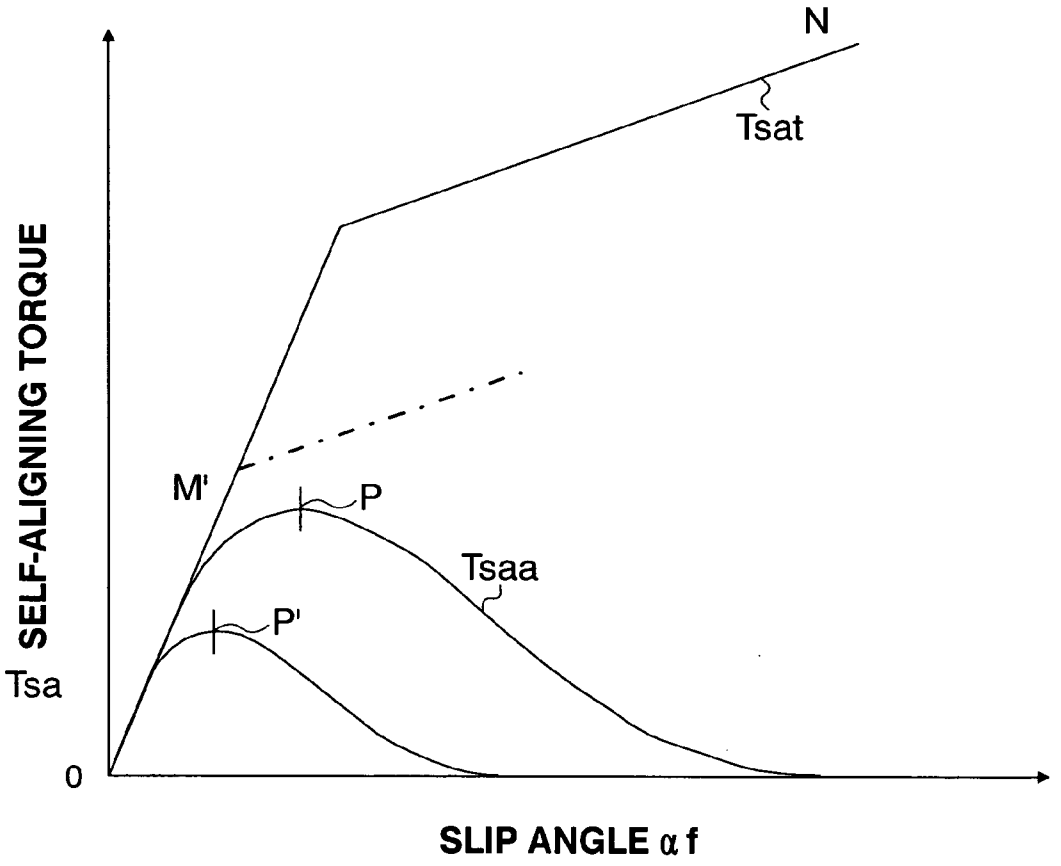


Figure 15

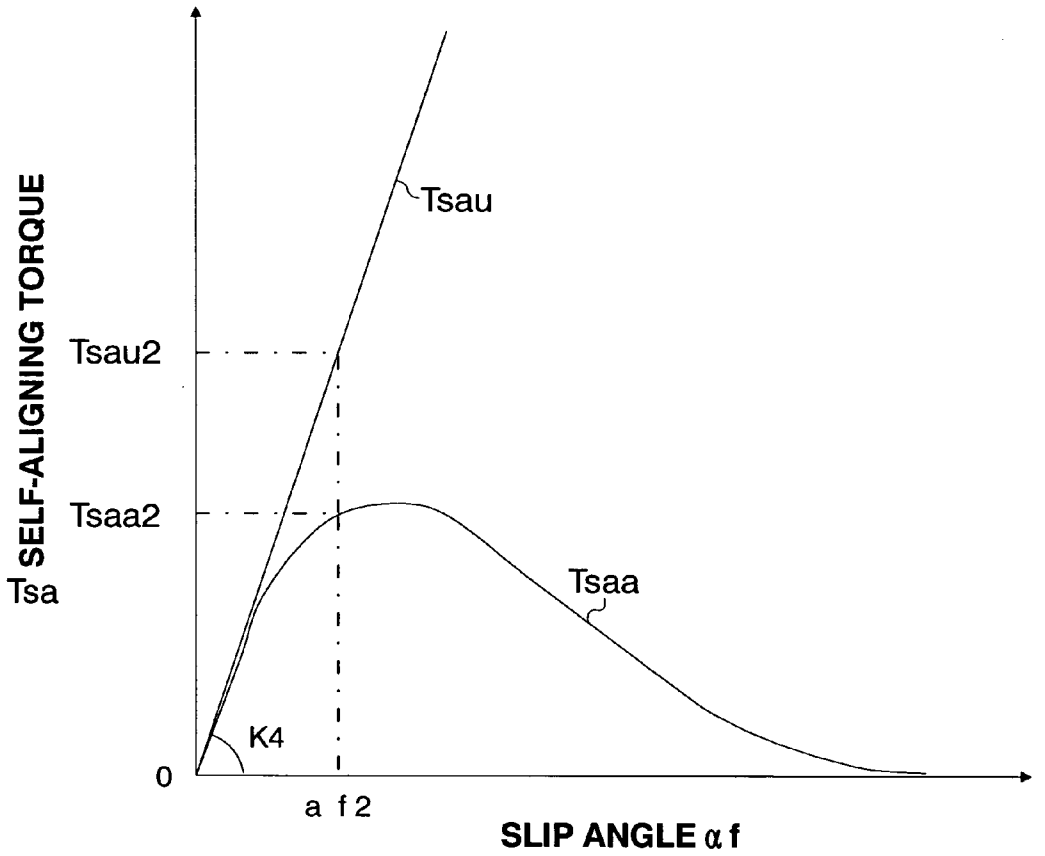

SELF-ALIGNING TORQUE
Tsa
Tsau
Tsau2
Tsaa2
Tsaa
K4
0
a f 2
SLIP ANGLE α f

Figure 16

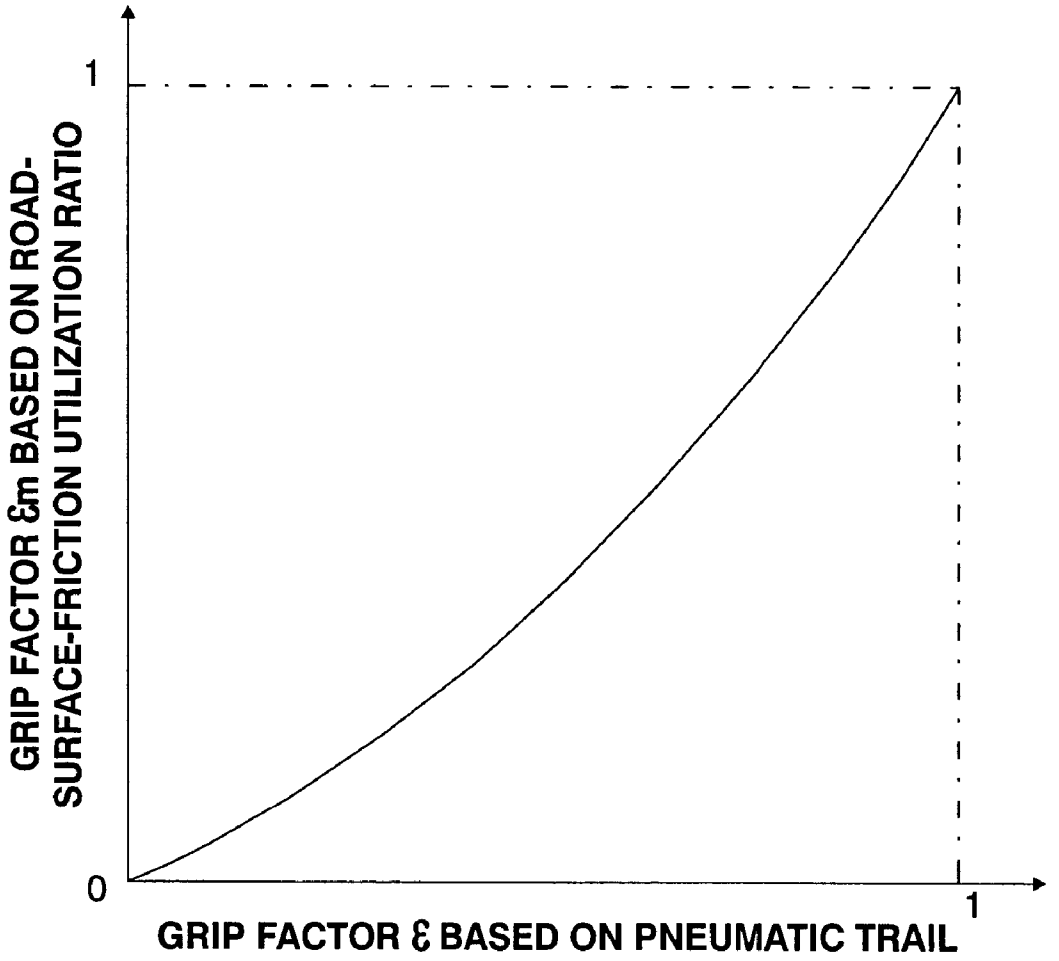

1
0
1
GRIP FACTOR &m BASED ON ROAD-SURFACE-FRICTION UTILIZATION RATIO
GRIP FACTOR & BASED ON PNEUMATIC TRAIL

Figure 17

INTEGRATED CONTROL APPARATUS FOR VEHICLE

INCORPORATION BY REFERENCE

[0001] The present application claims priority under 35 U.S.C. §119 to Japanese Patent Application No. 2003-344744 filed on Oct. 2, 2003. The content of the application is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to a integrated control apparatus for a vehicle.

[0004] 2. Description of the Related Art

[0005] A tire grip factor differs from a lateral force utilization factor or a lateral G utilization factor disclosed in Japanese Laid-Open Patent Application No. H11-99956. Specifically, the apparatus disclosed in this publication obtains the maximum lateral force that can be generated on a road surface, from the frictional coefficient μ of the road surface. This road-surface frictional coefficient μ is estimated on the basis of the dependency of cornering power Cp (defined to be a value of side force at a slip angle of 1 degree) on the road-surface frictional coefficient μ. However, cornering power Cp is influenced not only by road-surface frictional coefficient μ, but also by the shape of the contact surface of each tire (length and width of the contact surface), elasticity of tread rubber, and other factors. For example, in the case where water is present on the tread, or in the case where the elasticity of the tread rubber has changed because of tire wear or temperature change, the cornering power Cp changes even when the road-surface frictional coefficient μ is constant. As described above, the technique disclosed in the publication does not take into consideration the characteristics of wheels as tires.

[0006] In contrast, the grip factor is determined in consideration of characteristics of tires.

[0007] Here, the tire grip factor will be described in detail. In Automotive Technology Handbook (First Volume), Fundamentals and Theory, pp. 179-180 (published by Society of Automotive Engineers of Japan, Inc. on Dec. 1, 1990), a state in which a tire is rotating while sideslipping at a lateral slip angle α is described as shown in **FIG. 2**. That is, in **FIG. 2**, the tread of a tire illustrated by broken lines comes into contact with a road surface via a contact surface front end including point A of **FIG. 2** and adheres to the road surface up to point B, while moving toward the heading direction of the tire. When deformation force caused by a lateral shear deformation becomes equal to frictional force, the tread starts slipping, separates from the road surface at the rear end including point C, and returns to the original state. In this behavior, the force Fy (side force) generated by the entire contact surface is represented by the product of a laterally deformed area (a hatched portion in **FIG. 2**) of the tread and a lateral elastic constant of the tread per unit area. As shown in **FIG. 2**, the point of application of side force Fy is shifted rearward (leftward in **FIG. 2**) from the point O directly below the center line of the tire by e_n (pneumatic trail). Accordingly, moment Fy·en in effect at that time serves as self-aligning torque (Tsa) and acts in a direction for reducing the lateral slip angle α.

[0008] Next, the case where a tire is attached to a vehicle will be described with reference to **FIG. 3**, which is a simplified representation of the situation depicted in **FIG. 2**. In general, in order to facilitate return of a steering wheel, a caster angle is imparted to each steerable wheel of a vehicle to thereby provide a caster trail ec. Accordingly, the contact point of the wheel moves to point O', and a moment for returning the steering wheel is represented by Fy·(en+ec).

[0009] When the grip of the tire in the lateral direction decreases, and the slip region expands, the lateral deformation of the tread changes from the shape of A-B-C to the shape of A-D-C of **FIG. 3**. As a result, the point of application of side force Fy moves forward (from point H to point J of **FIG. 3**) in the vehicle heading direction. In other words, the pneumatic trail en decreases. Accordingly, even in the case where the same side force Fy acts on the tire, the pneumatic trail en and the self-aligning torque Tsa are large when the adhering region is large, and the slip region is small (i.e., the lateral grip of the tire is high). However, when the lateral grip of the tire is lost, and the slip region increase, the pneumatic trail en and the self-aligning torque Tsa decrease.

[0010] As described above, the level of lateral grip of a tire can be detected on the basis of change in the pneumatic trail en. Since change in the pneumatic trail en appears in the self-aligning torque Tsa, a grip factor, which represents the level of lateral grip of a front wheel of the vehicle, can be estimated on the basis of the self-aligning torque Tsa.

[0011] Incidentally, when the above-described various systems of a vehicle such as a steering system, a brake system, and a drive system are to be controlled in an integrated manner, conventionally, the grip factors of front wheels (wheels located frontward) are estimated so as to determine the conditions of tires (conditions of the front wheels), and control quantities are distributed to individual actuators of the respective systems in accordance with the conditions, whereby behavior stabilization control against disturbance to the vehicle is performed.

[0012] However, the above-described integrated control apparatus estimates the grip factors of only front wheels under the assumption that the vehicle is of a front-wheel-steering type. Specifically, since the conventional apparatus obtains the grip factors from the relation between self-aligning torque and slip angle of the front wheels, subtle differences in grip factor between left and right wheels and between front and rear wheels are estimated from, for example, lateral acceleration. Therefore, the conventional apparatus can be said not to estimate exact grip factors of individual wheels.

SUMMARY OF THE INVENTION

[0013] In view of the foregoing, an object of the present invention is to provide an integrated control apparatus for a vehicle having independently steerable wheels, which apparatus can estimate exact grip factors of the individual wheels, and which can integrally control actuators of at least two of a steering system, a brake system, and a drive system, by optimally distributing a control quantity in accordance with the grip factor of each wheel, to thereby improve the stability of the vehicle.

[0014] In order to achieve the above object, the present invention provides an integrated control apparatus for a

vehicle having vehicle behavioral-quantity detection, a vehicle behavioral-quantity detected device; an operation quantity detection device for detecting a quantity of driver's operation to a brake system, a drive system, and a steering system capable of independently steering individual wheels of the vehicle; a target vehicle behavioral-quantity calculation device for calculating a target vehicle behavioral-quantity in accordance with the detected vehicle behavioral-quantity and the detected operation quantity; a vehicle-control target value calculation device for calculating a vehicle-control target value on the basis of the target vehicle behavioral-quantity and the vehicle behavioral-quantity; an estimation device for estimating grip factors of the individual wheels to road surface; a distribution ratio setting device for setting, in accordance with the grip factors of the individual wheels, a distribution ratio for distribution of the vehicle-control target value among respective actuators of at least two systems among the brake system, the drive system, and the steering system; and a control device for controlling the actuators of at least two systems in accordance with the vehicle-control target value distributed among the actuators at the distribution ratio.

[0015] Preferably, the target vehicle behavioral-quantity calculation device calculates a target yaw rate, which serves as the target vehicle behavioral-quantity; and the vehicle-control target value calculation device calculates the vehicle-control target value on the basis of the target yaw rate and an actual yaw rate, which serves as the vehicle behavioral-quantity.

[0016] Preferably, the drive system includes drive force distribution device for distributing drive force between front wheels and rear wheels; and the control device controls an actuator of the drive force distribution device.

[0017] The estimation device may estimate each of the grip factors on the basis of change in pneumatic trail of the corresponding wheel.

[0018] Alternatively, the estimation device may estimate each of the grip factors on the basis of a road surface friction allowance level of the corresponding wheel.

[0019] Preferably, the estimation device includes steering-force-index detection device for detecting a steering force index including torque applied to the steering system including steering mechanisms for the individual wheels; a self-aligning torque estimation device for estimating a self-aligning torque produced by each wheel on the basis of the detected steering force index; a wheel index estimation device for estimating, on the basis of the vehicle behavioral-quantity detected by the vehicle behavioral-quantity detection device, at least one wheel index among wheel indexes including side force and slip angle of each wheel; and a grip factor estimating device for estimating the grip factor of each wheel on the basis of change in the self-aligning torque estimated by the self-aligning torque estimation device in relation to the wheel index estimated by the wheel index estimation device.

[0020] In this case, preferably, a reference self-aligning torque setting device is provided so as to set a reference self-aligning torque on the basis of the wheel index estimated by the wheel index estimation device and the self-aligning torque estimated by the self-aligning torque estimation device, wherein the grip factor estimating device estimates the grip factor of each wheel on the basis of results of comparison between the reference self-aligning torque set by the reference self-aligning torque setting device and the self-aligning torque estimated by the self-aligning torque estimation device.

[0021] In the case, preferably, the reference self-aligning torque setting device sets a reference self-aligning torque characteristic which is approximated from the characteristic of the self-aligning torque estimated by the self-aligning torque estimation device in relation to the wheel index estimated by the wheel index estimation device, the reference self-aligning torque characteristic being defined as a straight line in a coordinate system and passing through the origin of the coordinate system, and sets the reference self-aligning torque on the basis of the reference self-aligning torque characteristic.

[0022] Since the present invention is applied to a vehicle having wheels, all of which are independently steerable, the tire conditions of all the wheels can be determined accurately. Moreover, under the present invention, the grip factors of the wheels are estimated individually in such a vehicle having independently steerable wheels. Therefore, the respective actuators of at least two systems among the brake system, the drive system, and the steering system can be integrally controlled at an optimal distribution ratio determined on the basis of the grip factors of the wheels, whereby the stability of the vehicle can be improved.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] Various other objects, features and many of the attendant advantages of the present invention will be readily appreciated as the same becomes better understood by reference to the following detailed description of the preferred embodiments when considered in connection with the accompanying drawings, in which:

[0024] **FIG. 1** is a schematic, configurational block diagram of an integrated control apparatus according to a first embodiment of the present invention;

[0025] **FIG. 2** is a graph showing the relation between self-aligning torque and side force;

[0026] **FIG. 3** is a simplified view of the situation depicted in **FIG. 2**, showing the relation between self-aligning torque and side force;

[0027] **FIG. 4** is a control block diagram of an electronic control unit of an embodiment;

[0028] **FIG. 5** is a control block diagram of a grip factor calculation section of the electronic control unit;

[0029] **FIG. 6** is an explanatory view showing a 2-wheel vehicle model having a front wheel and a rear wheel;

[0030] **FIG. 7** is a control flowchart which the electronic control unit of an embodiment follows for execution of control;

[0031] **FIG. 8** is a graph showing a characteristic of side force vs. self-aligning torque;

[0032] **FIG. 9** is a graph showing a characteristic of self-aligning torque vs. actual reaction torque, for explanation of friction component of a steering mechanism;

[0033] **FIG. 10** is a block diagram of a grip factor calculation section, which estimates a grip factor from slip angle and self-aligning torque, in another embodiment of the present invention;

[0034] **FIG. 11** is a graph showing the relation of wheel side force and self-aligning torque with slip angle;

[0035] **FIG. 12** is a graph showing the relation of self-aligning torque with slip angle;

[0036] **FIG. 13** is a graph showing the relation of self-aligning torque with slip angle;

[0037] **FIG. 14** is a graph showing the relation of self-aligning torque with slip angle;

[0038] **FIG. 15** is a graph showing the relation of self-aligning torque with slip angle;

[0039] **FIG. 16** is a graph showing the relation of self-aligning torque with slip angle in another embodiment; and

[0040] **FIG. 17** is a graph showing the relation between grip factor ϵ based on pneumatic trail and grip factor ϵm based on road-surface-friction allowance level.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0041] An embodiment of the present invention will next be described with reference to FIGS. **1** to **9**. **FIG. 1** is a schematic configuration view of an integrated control apparatus for a vehicle according to the present embodiment. **FIG. 2** is a graph showing the relation between self-aligning torque and side force in an ordinary vehicle whose tires are rolling while skidding. **FIG. 3** is a simplified representation of the situation depicted in **FIG. 2** showing the relation between self-aligning torque and side force. **FIG. 4** is a block diagram of an electronic control unit **11**. **FIG. 5** is a block diagram of a grip factor calculation section **41**. **FIG. 6** is an explanatory view showing a 2-wheel vehicle model having a front wheel and a rear wheel. **FIG. 7** is a control flowchart. **FIG. 8** is a graph showing side force vs. self-aligning torque characteristics. **FIG. 9** is a graph showing self-aligning torque vs. steering-mechanism friction component characteristics in relation to correction at the time of estimation.

[0042] Drive System

[0043] First, the drive system of a vehicle **1** will be described. As shown in **FIG. 1**, a center differential **4** is connected to an engine EG of the vehicle **1** via a torque converter **2** and a transmission **3**. Front axles **5**R and **5**L are connected to the center differential **4** via an unillustrated front drive shaft and an unillustrated front differential. A front right wheel FRW is attached to the front axle **5**R, and a front left wheel FLW is attached to the front axle **5**L. A drive force distribution unit **7**, which serves as drive force distribution device, is connected to the center differential **4** via a rear drive shaft **6**. While the drive force distribution unit **7** is connected to the rear drive shaft **6**, a rear differential **9** is connected to the drive force distribution unit **7** via a drive pinion shaft **8**. A rear right wheel RRW and a rear left wheel RLW are connected to the rear differential **9** via a pair of rear axles **10**R and **10**L, respectively.

[0044] The drive force of the engine EG is transmitted to the center differential **4** via the torque converter **2** and the transmission **3** and further to the front right wheel FRW and the front left wheel FLW via the unillustrated front drive shaft, the unillustrated front differential, and the front axles **5**R and **5**L. When the rear drive shaft **6** and the drive pinion shaft **8** are connected in a torque-transmittable condition by means of the drive force distribution unit **7**, the drive force of the engine EG is transmitted to the rear right wheel RRW and the rear left wheel RLW via the rear drive shaft **6**, the drive pinion shaft **8**, the rear differential **9**, and the rear axles **10**R and **10**L.

[0045] The drive force distribution unit **7** includes an unillustrated known electromagnetic clutch mechanism of a wet multiple-disc type. The electromagnetic clutch mechanism has a plurality of clutch discs, which are frictionally engaged with each other or are disengaged from each other. When current corresponding to a control instruction value is supplied to an electromagnetic solenoid (not shown), which serves as an actuator, contained in the electromagnetic clutch mechanism, the clutch discs are frictionally engaged with each other, whereby torque is transmitted to the rear right wheel RRW and the rear left wheel RLW.

[0046] The frictional engagement force between the clutch discs varies depending on the quantity of current (intensity of current) supplied to the electromagnetic solenoid. By device of controlling the quantity of current supplied to the electromagnetic solenoid, the transmission torque between the front wheels FRW, FLW and the rear wheels RRW, RLW; i.e., the restraint force therebetween, can be adjusted. As the frictional engagement force between the clutch discs increases, the transmission torque between the front wheels and the rear wheels increases. On the other hand, as the frictional engagement force between the clutch discs decreases, the transmission torque between the front wheels and the rear wheels decreases. The electronic control unit **11** starts and stops supply of current to the electromagnetic solenoid and adjusts the quantity of current supplied to the electromagnetic solenoid. When supply of current to the electromagnetic solenoid is shut off, the clutch discs are disengaged from each other, thereby shutting off transmission of torque to the rear wheels (rear right wheel RRW and rear left wheel RLW). The electronic control unit **11** controls the frictional engagement force between the clutch discs in the drive force distribution unit **7**, to thereby select a 4-wheel drive mode or a 2-wheel drive mode. Also, in the 4-wheel drive mode, the electronic control unit **11** controls the drive force distribution ratio (torque distribution ratio) between the front wheels and the rear wheels. In the present embodiment, the drive force distribution rate between the front wheels and the rear wheels can be adjusted in the range of 100:0 to 50:50.

[0047] The vehicle **1** has an accelerator pedal AP. An accelerator sensor AS inputs a detection signal corresponding to a stepping-on measurement of the accelerator pedal AP to the electronic control unit **11** mounted on the vehicle **1**. In accordance with the detection signal, the electronic control unit **11** controls the throttle opening of the engine EG. As a result, the output of the engine EG is controlled in accordance with the stepping-on measurement of the accelerator pedal AP. Wheel speed sensors **12** to **15** for detecting the rotational speed of the corresponding wheels (wheel speed) are provided respectively on the front right wheel FRW, the front left wheel FLW, the rear right wheel RRW, and the rear left wheel RLW. Detection signals (wheel

speeds Vfr, Vfl, Vrr, and Vrl) from the corresponding wheel speed sensors **12** to **15** are output to the electronic control unit **11**.

[**0048**] Steering System

[**0049**] Next, a steering system of the vehicle **1** will be described. The steering system includes a steering wheel SW; steering actuators **16**FR, **16**FL, **16**RR, and **16**RL provided for the individual wheels; and steering gears **17**FR, **17**FL, **17**RR, and **17**RL. The steering wheel SW is not mechanically connected to the steering actuators. When the steering actuators **16**FR, **16**FL, **16**RR, and **16**RL are driven, the steering gears **17**FR, **17**FL, **17**RR, and **17**RL transmit respective outputs of the steering actuators to the front right wheel FRW, the front left wheel FLW, the rear right wheel RRW, and the rear left wheel RLW, to hereby change their steered angles.

[**0050**] The steering gears **17**FR, **17**FL, **17**RR, and **17**RL constitute individual steering mechanisms for the individual wheels in cooperation with the steering actuators **16**FR, **16**FL, **16**RR, and **16**RL corresponding thereto.

[**0051**] Each of the steering actuators is formed of an electric motor such as a well known brushless motor. The steering gear **17**FR (**17**FL, **17**RR, **17**RL) is connected to the output shaft of the corresponding steering actuator, and has a mechanism for converting rotation of the output shaft to linear motion of a corresponding rod **18**FR (**18**FL, **18**RR, **18**RL). The rods **18**FR **18**FL, **18**RR, and **18**RL are connected to the front right wheel FRW, the front left wheel FLW, the rear right wheel RRW, and the rear left wheel RLW, via tie rods **19**FR, **19**FL, **19**RR, and **19**RL, and unillustrated knuckle arms. With this mechanism, outputs of the steering actuators are transmitted to the front right wheel FRW, the front left wheel FLW, the rear right wheel RRW, and the rear left wheel RLW, to thereby change their steered angles. The steering gears **17**FR, **17**FL, **17**RR, and **17**RL have a well-known structure. No limitation is imposed on their structure, so long as the steering gears **17**FR, **17**FL, **17**RR, and **17**RL can change the steered angles of the corresponding wheels in accordance with outputs of the steering actuators. Notably, the wheel alignment is adjusted in such a manner that when the steering actuators are not driven, the individual wheels are returned to a neutral steering position by device of self-aligning torque.

[**0052**] The steering wheel SW is connected to a steering shaft SWa and a steering reaction imparting unit SST. The steering reaction imparting unit SST includes a steering reaction actuator (not shown). The steering reaction actuator is formed of an electric motor, such as a brushless motor, which has an output shaft integrally connected to the steering shaft SWa.

[**0053**] A steering angle sensor SS is provided on the steering shaft SWa, and outputs a detection signal (steering angle signal) which is indicative of steering angle θ of the steering wheel SW and is fed to the electronic control unit **11**. The steering angle sensor SS serves as operation amount detection device for detecting the amount of a driver's operation imparted to the steering system (steering angle θ).

[**0054**] Further, a steering torque sensor TS is attached to the steering shaft SWa, and outputs a detection signal which is indicative of steering torque of the steering wheel SW and is fed to the electronic control unit **11**. The direction of steering can be determined on the basis of the sign of the steering toque signal output from the steering torque sensor TS.

[**0055**] Moreover, steered angle sensors **13***a* to **13***d* are provided so as to detect respective amounts of movement of the rods **18**FR, **18**FL, **18**RR, and **18**RL as steered angles of the wheels, and the steered angle sensors **13***a* to **13***d* output detection signals which are indicative of respective steered angles of the individual wheels and are fed to the electronic control unit **11**. Each of the steered angle sensors **13***a* to **13***d* is a potentiometer. In addition, torque sensors TS**1** to TS**4** are provided so as to detect respective torques of the steering actuators **16**FR, **16**FL, **16**RR, and **16**RL as steering forces for steering the individual wheels, and the torque sensors TS**1** to TS**4** output detection signals which are indicative of respective torques and are fed to the electronic control unit **11**. The torque sensors TS**1** to TS**4** are current sensors adapted to detect load currents of the steering actuators **16**FR, **16**FL, **16**RR, and **16**RL.

[**0056**] Brake System

[**0057**] Next, the brake system of the vehicle **1** will be described. The brake system includes wheel cylinders **24** to **27**, which serve as braking device and are provided respectively for the front right wheel FRW, the front left wheel FLW, the rear right wheel RRW, and the rear left wheel RLW, a hydraulic circuit **28**, an unillustrated master cylinder; and a brake pedal BP for driving the master cylinder. The hydraulic circuit **28** includes a reservoir, an oil pump, and various valve device. In an ordinary state, the brake fluid pressures of the wheel cylinders **24** to **27** are controlled via the hydraulic circuit **28** by device of the brake fluid pressure of the master cylinder, which is driven in accordance with the stepping-on force of the brake pedal BP. The brake fluid pressure of each of the wheel cylinders **24** to **27** exerts a braking force on the corresponding wheel.

[**0058**] In execution of predetermined control, such as antilock braking control, the electronic control unit **11** controls solenoid valves (unillustrated) of the hydraulic circuit **28** on the basis of various control parameters, which will be described later, to thereby individually control the brake fluid pressures of the wheel cylinders **24** to **27**; for example, to increase, decrease, or hold the brake fluid pressures. A brake stepping-on-force sensor BS inputs, to the electronic control unit **11**, a signal corresponding to a stepping-on force when the brake pedal BP is stepped on. The electronic control unit **11** detects, from the signal, a stepping-on force of the brake pedal BP.

[**0059**] Fluid pressure sensors **29** to **32** detect the brake fluid pressures of the corresponding wheel cylinders **24** to **27** and input detection signals indicative of the detected brake fluid pressures to the electronic control unit **11**. The electronic control unit **11** detects, from the detection signals, the braking conditions of the front right wheel FRW, the front left wheel FLW, the rear right wheel RRW, and the rear left wheel RLW.

[**0060**] Control System

[**0061**] Next, control system of the vehicle **1** will be described. The electronic control unit **11** includes a digital computer. The electronic control unit **11** may assume the form of a single ECU (electronic control unit) or the form of a plurality of ECUs corresponding to controls to be per-

formed. The ECU includes a CPU and a memory **11***a*, which includes ROM and RAM. The electronic control unit **11** stores in the memory **11***a*, as control parameters, detection signals mentioned below and associated with behavioral conditions of the vehicle **1**. On the basis of the control parameters, the electronic control unit **11** integrally controls the steering system, the drive system, and the brake system of the vehicle **1**, to thereby stabilize the running posture of the vehicle **1**; i.e., to improve vehicle stability. The electronic control unit **11** serves as control device.

[**0062**] Outline of Engine Control

[**0063**] A detection signal indicative of the stepping-on measurement of the accelerator pedal AP is input to the electronic control unit **11** from the accelerator sensor AS. On the basis of the stepping-on measurement of the accelerator pedal AP, the electronic control unit **11** calculates the throttle opening of the engine EG and outputs a control signal indicative of the throttle opening to the engine EG, to thereby control the engine EG.

[**0064**] Calculation of Vehicle Speed

[**0065**] Detection signals indicative of the wheel speeds Vfr, Vfl, Vrr, and Vrl of the front right wheel FRW, the front left wheel FLW, the rear right wheel RRW, and the rear left wheel RLW, respectively, are input to the electronic control unit **11** from the wheel speed sensors **12** to **15**. On the basis of the input detection signals, the electronic control unit **11** calculates the wheel speeds of the front right wheel FRW, the front left wheel FLW, the rear right wheel RRW, and the rear left wheel RLW and stores the calculated values in the memory **11***a* as control parameters. On the basis of the calculation results, the electronic control unit **11** calculates the vehicle speed V of the vehicle **1** and stores the calculated value in the memory **11***a* as a control parameter. In the present embodiment, the average of the wheel speeds Vfr, Vfl, Vrr, and Vrl is calculated and taken as the vehicle speed V (=(Vfr+Vfl+Vrr+Vrl)/4).

[**0066**] The electronic control unit **11** serves as vehicle behavioral quantify detection device for detecting the vehicle speed V, which serves as a vehicle behavioral quantify.

[**0067**] Brake Control

[**0068**] A detection signal indicative of the stepping-on measurement of the brake pedal BP is input to the electronic control unit **11** from the brake stepping-on-force sensor BS. On the basis of the input detection signal, the electronic control unit **11** calculates a stepping-on measurement. In execution of predetermined control, such as antilock braking control, on the basis of the calculated stepping-on measurement, the electronic control unit **11** calculates a required brake fluid pressure of each of the wheel cylinders **24** to **27** and outputs control instruction values for generating the brake fluid pressures to a drive circuit section **47** of the hydraulic circuit **28** for driving the solenoid valves. Also, detection signals indicative of brake fluid pressures of the wheel cylinders **24** to **27** are input to the electronic control unit **11** from the fluid pressure sensors **29** to **32**. On the basis of the detection signals, the electronic control unit **11** calculates the brake fluid pressures of the wheel cylinders **24** to **27** and stores the calculated values in the memory **11***a* as control parameters. The electronic control unit **11** performs feedback control by device of using detected brake fluid pressures as feedback quantities.

[**0069**] As shown in **FIG. 1**, the vehicle **1** has a yaw rate sensor **33**, a longitudinal acceleration sensor **34**, and a lateral acceleration sensor **35**. The yaw rate sensor **33** inputs a detection signal indicative of an actual yaw rate γ, which is an actual yaw rate of the vehicle **1**, to the electronic control unit **11**. On the basis of the detection signal, the electronic control unit **11** calculates the actual yaw rate γ and stores the calculated value in the memory **11***a* as a control parameter. The longitudinal acceleration sensor **34** inputs a detection signal indicative of an actual longitudinal acceleration Gx, which is an actual longitudinal acceleration of the vehicle **1**, to the electronic control unit **11**. On the basis of the detection signal, the electronic control unit **11** calculates the actual longitudinal acceleration Gx and stores the calculated value in the memory **11***a* as a control parameter. The lateral acceleration sensor **35** inputs a detection signal indicative of an actual lateral acceleration Gy, which is an actual lateral acceleration of the vehicle **1**, to the electronic control unit **11**. On the basis of the detection signal, the electronic control unit **11** calculates the actual lateral acceleration Gy and stores the calculated value in the memory **11***a* as a control parameter.

[**0070**] The yaw rate sensor **33** serves as vehicle behavioral-quantity detection device for detecting the actual yaw rate y.

[**0071**] Steering Control

[**0072**] The electronic control unit **11** uses the above-mentioned various detection signals as various control parameters, and independently controls the steering actuators **16**FR, **16**FL, **16**RR, and **16**RL on the basis of these control parameters. Further, the electronic control unit **11** controls the unillustrated steering reaction actuator of the steering reaction imparting unit SST on the basis of the various control parameters.

[**0073**] Control Block Diagram

[**0074**] Next, control blocks of the integrated control apparatus will be described with reference to the control block diagram of **FIG. 4**. In **FIG. 4**, reference numerals **40** to **45** and a**1** to a**3** denote control blocks in the software system of the electronic control unit **11**; and drive circuit sections **46** to **48** and subsequent blocks are those in the hardware system.

[**0075**] Target-Value Calculation Section **40**

[**0076**] The target-value calculation section **40** calculates a target yaw rate γ*, which is a target vehicle behavioral-quantity, on the basis of the vehicle speed V and the actual steering angle δ. Specifically, the target-value calculation section **40** calculates the target yaw rate γ* and the target slip angle β* (target skid angle) of the vehicle **1** on the basis of equations of motion of a vehicle shown below.

$$mV\frac{d\beta}{dt} + 2(K_f + K_r)\beta\left[mV + \frac{2}{V}(l_f K_f - l_r K_r)\right]\gamma = 2K_f\delta \quad (1)$$

$$2(l_f K_f - l_r K_r)\beta + I\frac{d\gamma}{dt} + \frac{2(l_f^2 K_f + l_r^2 K_r)}{V}\gamma = 2l_f K_f\delta \quad (2)$$

[0077] Eq. (1) and Eq. (2) are known equations of motion of the vehicle **1** that is modeled as a 2-wheel vehicle having a front wheel and a rear wheel as shown in **FIG. 6**. In Eqs. (1) and (2), m is inertial mass of the vehicle; V is vehicle speed; β is vehicle-body skid angle (vehicle-body slip angle); Kf is front cornering power; Kr is rear cornering power; lf is distance between the front axle and the center of gravity P0 of the vehicle; lr is distance between the rear axle and the center of gravity of the vehicle; δ is actual steering angle; and I is yawing moment of inertia. In **FIG. 6**, βf is front-wheel skid angle (front-wheel slip angle), and βr is rear-wheel skid angle (rear-wheel slip angle). Additionally, x and y represent coordinate axes of a coordinate system fixed to the vehicle and passing through the center of gravity of the vehicle. Notably, during ordinary travel in which the vehicle does not exhibit a tendency of under-steer or a tendency of over-steer, since the front right wheel FRW and the front left wheel FLW are controlled by the electronic control unit **11** such that they are steered by the same angle, the actual steering angle δ coincides with the steered angles of the front right wheel FRW and the front left wheel FLW detected by the steered angle sensors **13***a* and **13***b*.

[0078] The target-value calculation section **40** calculates a yaw rate difference Δγ between the actual yaw rate γ and the target yaw rate γ* and uses the calculated yaw rate difference Δγ as a vehicle-control target value. The target-value calculation section **40** serves as target vehicle behavioral-quantity calculation device and vehicle-control target value calculation device.

[0079] Grip Factor Calculation Section **41**

[0080] As shown in **FIG. 5**, the grip factor calculation section **41** includes reaction torque detection device **M3**, friction torque estimation device **M5**, self-aligning torque estimation device **M6**, self-aligning torque gradient-at-origin estimation device **M10**, reference self-aligning torque setting device **M11**, and grip factor estimation device **M12**. The grip factor calculation section **41** estimates grip factor ϵ of each wheel by use of these means. The grip factor calculation section **41** serves as estimation device for estimating the grip factor of each wheel.

[0081] In the following description, in order to simplify the description, estimation of grip factor ϵ of the front right wheel FRW is described, and estimation of grip factors of the remaining wheels is omitted, because when the items in relation to the front right wheel FRW in the following description are read as those for the remaining wheels, the following description can be read as description for estimation of grip factors of the remaining wheels.

[0082] First, outline of grip factor estimation will be described. As is apparent from **FIGS. 2 and 3**, the self-aligning torque in relation to a side force acting on the front right wheel FRW exhibits a characteristic as represented by Tsaa in **FIG. 8**. When Tsaa represents the actual self-aligning torque, and Fyf represents the side force serving as a wheel index, Tsaa=Fyf·(en+ec). Thus, the nonlinear characteristic of the actual self-aligning torque Tsaa in relation to the side force Fyr directly represents a change in the pneumatic trail en. Hence, the inclination K1 of the actual self-aligning torque Tsaa as measured near the origin 0 in relation to the side force Fyf (where the wheel is in grip condition) is identified; i.e., a self-aligning torque characteristic in complete grip condition (characteristic of reference self-aligning torque Tsao) is obtained. The initial value of the inclination K1 is an experimentally obtained, predetermined value. Preferably, during normal run, during which the grip factor is high, the inclination K1 that assumes the initial value is corrected as appropriate. The actual self-aligning torque Tsaa is calculated as described later.

[0083] The grip factor ϵ of each wheel is estimated on the basis of the reference self-aligning torque Tsao and the actual self-aligning torque Tsaa. For example, when the side force is Fyf1, the reference self-aligning torque Tsao assumes a value of Tsao1 (=K1·Fyf1), and the actual self-aligning torque Tsaa assumes a value of Tsaa1, the grip factor ϵ is obtained as ϵ=Tsaa1/Tsao1.

[0084] As described above, the grip factor of the wheel can be estimated on the basis of a change in self-aligning torque (actual self-aligning torque Tsaa) in relation to the side force Fyf.

[0085] Action of Configuration Adapted to Estimate Grip Factor

[0086] In **FIG. 5**, torque detection device **M2** is configured as steering-force index detection device for detecting a steering force index. Specifically, the torque detection device **M2** is formed of the torque sensors **TS1** to **TS4**. In the case of the front right wheel FRW, the torque sensor **TS1** serves as the torque detection device **M2**.

[0087] On the basis of the detection result of the torque detection device **M2**, the reaction torque detection device **M3** detects reaction torque, which is input to the self-aligning torque estimation device **M6**. The steering angle sensor SS, which serves as steering-angle detection device **M4** of **FIG. 5**, detects the steering angle θ. On the basis of the detected steering angle θ, the friction torque estimation device **M5** estimates friction torque Tfrc of a steering mechanism formed by the steering gear **17**FR, etc., which is input to the self-aligning torque estimation device **M6**. On the basis of the input reaction torque and friction torque, the self-aligning torque estimation device **M6** estimates the actual self-aligning torque Tsaa, which is generated on the wheels.

[0088] Specifically, when a steering operation is performed, the steering angle θ is detected by the steering angle sensor SS, and the steering actuator **16**FR is controlled in accordance with the steering angle θ. That is, the electronic control unit **11** calculates a target position (target steering angle) corresponding to the steering angle θ, generates a control instruction value needed for steering, on the basis of the difference between the target position and the steered angle detected by the steered angle sensor **13***a*, and controls the steering actuator **16**FR in accordance with the instruction value. When the vehicle does not exhibit a tendency of under-steer or a tendency of over-steer, the front left wheel FLW is controlled to have the same steered angle as that of the front right wheel FRW, and the left and right rear wheels are controlled in such a manner that their steered angles become zero. In the case where the steered angles of the left and right rear wheels have changed as a result of a certain control, the left and right rear wheels may have non-zero steered angles.

[0089] In this case, self-aligning torque generated on the front right wheel FRW balances a value (torque) obtained by subtracting the friction torque Tfrc of the steering mecha-

nism from the torque of the steering actuator **16**FR. Accordingly, the actual self-aligning torque Tsaa is obtained as Tsaa=Teps−Tfrc, where Teps is torque which is output from the steering actuator **16**FR and is detected by the torque sensor TS**1**. Tfrc is a torque component (friction torque) caused by friction of the steering mechanism.

[**0090**] As mentioned above, Tfrc is a friction component of the steering mechanism; i.e., a torque component caused by friction of the steering mechanism. In the present embodiment, Tfrc is subtracted from Teps for correction, to thereby obtain the actual self-aligning torque Tsaa.

[**0091**] The above-mentioned correction method will be described with reference to **FIG. 9**. When the vehicle is running straight, the actual reaction torque (Teps) is zero. When the driver starts steering operation by turning the steering wheel SW, actual reaction torque begins to be generated. At this time, first, torque to cancel Coulomb friction of the steering mechanism is generated. Next, the front wheels (tires) begin to be turned, and thus self-aligning torque begins to be generated.

[**0092**] In the initial stage where steering operation is initiated in the straight running state, as represented by the segment O-A of **FIG. 9**, self-aligning torque is not generated in relation to an increase in actual reaction torque. Thus, an estimated value of self-aligning torque is output as the actual self-aligning torque Tsaa that increases along a slight inclination with actual reaction torque (strictly speaking, the actual self-aligning torque Tsaa is a corrected, estimated value, but the term "estimated" is omitted). When the steering wheel SW is turned further, and thus actual reaction torque falls outside the friction torque region, the actual self-aligning torque Tsaa is output along the segment A-B of **FIG. 9**. When the steering wheel SW is turned back, and thus actual reaction torque decreases, the actual reaction torque Tsaa is output in such a manner as to decrease with actual reaction torque along a slight inclination as represented by the segment B-C of **FIG. 9**. As in the case where the steering wheel SW is turned further, when actual reaction torque falls outside the friction torque region, the actual self-aligning torque Tsaa is output along the segment C-D of **FIG. 9**.

[**0093**] Next, side force estimation device M**9** will be described.

[**0094**] The side force estimation device M**9** receives detection signals from lateral acceleration detection device M**7** and yaw rate detection device M**8**, which serve as vehicle behavioral-quantity detection device. In the present embodiment the lateral acceleration sensor **35** serves as the lateral acceleration detection device M**7**, and the yaw rate sensor **33** serves as the yaw rate detection device M**8**.

[**0095**] On the basis of detection signals from the lateral acceleration detection device M**7** and the yaw rate detection device M**8**, the side force estimation device M**9** estimates the side force Fyf acting on the wheel. Specifically, on the basis of the output results of the lateral acceleration detection device M**7** and the yaw rate detection device M**8**, the side force Fyf is estimated as $Fyf=(Lr\cdot m\cdot Gy+Iz\cdot d\gamma/dt)/L$, where Lr is distance between the center of gravity and the rear axle; m is the mass of the vehicle; L is wheel base; Iz is the yawing moment of inertia; Gy is lateral acceleration; and $d\gamma/dt$ is a value obtained by differentiating the yaw rate with respect to time.

[**0096**] The side force estimation device M**9** serves as wheel index estimation device. The self-aligning torque gradient-at-origin estimation device M**10** estimates the gradient of self-aligning torque as measured near the origin. Specifically, on the basis of the actual self-aligning torque Tsaa estimated by the self-aligning torque estimation device M**6** and the side force Fyf estimated by the side force estimation device M**9**, the self-aligning torque gradient-at-origin estimation device M**10** estimates the self-aligning torque gradient-at-origin K1, which is the gradient of self-aligning torque as measured near the origin in **FIG. 8**.

[**0097**] On the basis of the self-aligning torque gradient-at-origin K1 and the side force Fyf, the reference self-aligning torque setting device M**11** calculates the reference self-aligning torque Tsao as $Tsao=K1\cdot Fyf$.

[**0098**] On the basis of the reference self-aligning torque Tsao and the actual self-aligning torque Tsaa, the grip factor estimation device M**12** estimates the grip factor ϵ as $\epsilon=Tsaa/Tsao$.

[**0099**] After the grip factor of one wheel is estimated, the grip factors of the remaining wheels are successively estimated in the same manner. Notably, in the following description, the grip factors of the front right wheel FRW, the front left wheel FLW, the rear right wheel RRW, and the rear left wheel RLW may be represented by $\epsilon 1$ to $\epsilon 4$, respectively.

[**0100**] Optimal-Distribution Processing Section **42**

[**0101**] The optimal-distribution processing section **42** uses the yaw rate difference $\Delta\gamma$ calculated by the target-value calculation section **40** as a vehicle-control target value and optimally distributes the vehicle-control target value among the steering system, the drive system, and the brake system on the basis of the grip factors $\epsilon 1$ to $\epsilon 4$ of the four wheels estimated in the grip factor calculation section **41**.

[**0102**] Distribution ratios among the steering, drive, and brake systems in optimal distribution processing are stored in the ROM in the form of map. The map is prepared beforehand by device of a test or the like such that the distribution ratios vary in accordance with the magnitude of the absolute value of the yaw rate difference $\Delta\gamma$ and whether the yaw rate difference $\Delta\gamma$ is positive or negative, and such that a wheel corresponding to the smallest one of the grip factors $\epsilon 1$ to $\epsilon 4$ is increased in grip factor. The optimal-distribution processing section **42** performs optimal distribution processing on the basis of the map. As a result of optimal distribution processing, the optimal-distribution processing section **42** generates a control target value for the drive system, a control target value for the brake system, and a control target value for the steering system in equal number to objects of control. The generated control target values are output to adders a**1** to a**3** as instruction values. Hereinafter, an instruction value for the drive system is called a "control instruction value At," a control value for the brake system is called a "control instruction value Bt," and an instruction value for the steering system is called a "control instruction value Ct." In the present embodiment, the number of objects of control is one for the drive system, but four (wheel cylinders **24** to **27**) for the brake system, and four (steering actuators **16**FR, **16**FL, **16**RR, and **16**RL) for the steering system.

[**0103**] The optimal-distribution processing section **42** serves as distribution-ratio-setting device.

[0104] Drive Control Section

[0105] A drive control section **43** of the drive system shown in **FIG. 4** functions as follows. A known control parameter for judging the behavioral condition of the vehicle **1** is input to the drive control section **43**. On the basis of the control parameter, the drive control section **43** sets a control instruction value Aw and outputs the control instruction value Aw to the adder a**1**. Examples of the control parameter include the vehicle speed V, the wheel speeds Vfr, Vfl, Vrr, and Vrl, and the throttle opening of the engine EG based on the stepping-on measurement of the accelerator pedal AP. The adder a**1** adds the control instruction value Aw and the control instruction value At and outputs the obtained sum (Aw+At) to the drive circuit section **46** of the drive force distribution unit **7** as a new control instruction value. On the basis of the new control instruction value (Aw+At), the drive circuit section **46** supplied the electromagnetic solenoid (not shown) of the drive power distribution unit **7** with current corresponding to the control instruction value (Aw+At), thereby adjusting the frictional engagement force between the clutch discs. As a result, the drive force distribution unit **7** distributes drive power corresponding to the control instruction value (Aw+At) to the rear wheels, thereby transmitting torque to the rear right wheel RRW and the rear left wheel RLW.

[0106] Since drive power is distributed between the front wheels and the rear wheels in accordance with a control instruction value that improves the grip factor, a wheel whose grip factor is the lowest among the wheels is improved in the grip factor, thereby ensuring running stability.

[0107] Braking Control Section

[0108] The braking control section **44** of the brake system shown in **FIG. 4** functions as follows. A known control parameter for braking the vehicle **1** is input to the braking control section **44**. On the basis of the control parameter, the braking control section **44** calculates the individual brake fluid pressures of the wheel cylinders **24** to **27**. Control instruction values Bw for generating the corresponding brake fluid pressures are output to the corresponding adders a**2**. Examples of the control parameter include the vehicle speed V, the wheel speeds Vfr, Vfl, Vrr, and Vrl, and a stepping-on measurement detected by the brake stepping-on-force sensor BS.

[0109] In **FIG. 4**, in order to simplify the description, only a single adder a**2** and a single drive circuit section **47** are representatively illustrated. In actuality, adders a**2** and drive circuit sections **47** are provided in equal number with the wheel cylinders **24** to **27**. As will be described later, the adders a**2** output corresponding control instruction values to the corresponding drive circuit sections **47**, and the drive circuit sections **47** drives the corresponding wheel cylinders **24** to **27**. The below description will representatively discuss a single object of control.

[0110] The adder a**2** adds the control instruction value Bw and the control instruction value Bt and outputs the obtained sum (Bw+Bt), as a new control instruction value, to the drive circuit section **47** for a solenoid valve of the hydraulic circuit **28**. On the basis of the new control instruction value (Bw+Bt), the drive circuit section **47** controls the solenoid valve of the hydraulic circuit **28**, thereby controlling the brake fluid pressure of the corresponding wheel cylinder **24**, **25**, **26**, or **27**. As a result, the wheel cylinder **24**, **25**, **26**, or **27** brakes the corresponding wheel in accordance with the control instruction value (Bw+Bt).

[0111] As a result, by means of braking any appropriate wheel, a wheel whose grip factor is the lowest among the wheels is improved in grip factor, thereby ensuring running stability.

[0112] Steering Control Section

[0113] The steering control section **45** shown in **FIG. 4** functions as follows. A known control parameter for judging the behavioral condition of the vehicle **1** is input to the steering control section **45**. On the basis of the control parameter, the steering control section **45** sets a control instruction value Cw and outputs the control instruction value Cw to the adder a**3**. Examples of the control parameter include the steering angle θ, the vehicle speed V, the wheel speeds Vfr, Vfl, Vrr, and Vrl, and a detection signal (steered angle signal) indicative of the steered angle of each wheel.

[0114] Notably, in **FIG. 4**, in order to simplify the description, a single adder a**3** and a single drive circuit section **48** are shown as representatives; however, four adders a**3** and four drive circuits **48** are provided for the steering actuators **16**FR, **16**FL, **16**RR, and **16**RL. As described later, control instruction values output from the adders a**3** are fed to the corresponding drive circuits **48**, and the drive circuits **48** drive the corresponding steering actuators. Accordingly, in the following description, one object of control (i.e., the single adder a**3** and the single drive circuit section **48**) will be described as a representative.

[0115] For the front right wheel FRW and the front left wheel FLW, the steering control section **45** calculates a target position (target steering angle) for the wheels corresponding to the steering angle θ, and generates a control instruction value needed for steering, on the basis of the difference between the target position and the steered angle detected by the steered angle sensor **13***a*.

[0116] Further, the steering control section **45** detects whether the vehicle exhibits a tendency of under-steer or a tendency of over-steer, from the speed differential between inside and outside wheels, the steered angle of the front wheels, etc., on the basis of steered angle signals of the individual wheels, and wheel speeds of the individual wheels. When the vehicle **1** travels along a curve and exhibits a tendency of under-steer, the steering control section **45** calculates a target steering angle so that a rear wheel located on the outer side of a curved travel path of the vehicle is directed outward of the vehicle **1**. For example, when the vehicle **1** makes a left turn, the steering control section **45** calculates a target steering angle so that the rear right wheel RRW is directed outward of the vehicle **1**.

[0117] When the steering control section **45** detects a tendency of over-steer, the steering control section **45** calculates a target steering angle so that a rear wheel located on the outer side of a curved travel path of the vehicle is directed inward of the vehicle **1**. For example, when the vehicle **1** makes a left turn, the steering control section **45** calculates a target steering angle so that the rear right wheel RRW is directed inward of the vehicle **1**.

[0118] The steering control section **45** outputs to the adder a**3** a control instruction value Cw corresponding to the

calculated target steering angle. The adder a**3** calculates the sum of the control instruction value Cw and a control instruction value Ct, and outputs the sum (Cw+Ct) to the drive circuit **48** for the steering actuator **16**RR (**16**RL), as a new control instruction value. On the basis of the new control instruction value (Cw+Ct), the drive circuit **48** supplies to the steering actuator **16**RR (**16**RL) current corresponding to the new control instruction value (Cw+Ct), to thereby steer the rear right wheel RRW (rear left wheel RLW).

[**0119**] As a result, in the case of a tendency of under-steer, an inner moment is generated in the vehicle **1**, whereby the slip angle decreases, and stable travel is realized. At this time, among the wheels, the grip factor of a wheel having the smallest grip factor is increased, and thus, more stable travel is realized.

[**0120**] Meanwhile, in the case of a tendency of over-steer, an outer moment is generated in the vehicle **1**, whereby the slip angle decreases, and stable travel is realized. At this time, among the wheels, the grip factor of a wheel having the smallest grip factor is increased, and thus, more stable travel is realized.

[**0121**] **FIG. 7** is a control flowchart that the electronic control unit **11** of the present embodiment follows for execution of control.

[**0122**] In step S**100**, the electronic control unit **11** performs initialization. In step S**200**, the electronic control unit **11** receives detection signals from various sensors, and communication signals from other control units (not shown) In step S**300**, the target-value calculation section **40** calculates a target vehicle behavioral-quantity; i.e., the target yaw rate γ^*. In step S**400**, the target-value calculation section **40** calculates the yaw rate difference $\Delta\gamma$ between the actual yaw rate γ and the target yaw rate γ^* as a vehicle-control target value. In step S**500**, the grip factor calculation section **41** estimates the grip factors $\epsilon 1$ to $\epsilon 4$. In step S**600**, the optimal-distribution processing section **42** performs optimal distribution processing for distribution of the vehicle-control target value among actuators and generates the control instruction values At, Bt, and Ct. In step S**700**, the electronic control unit **11** outputs the control instruction values for the steering, brake, and drive systems to the actuators of the systems.

[**0123**] The present embodiment is characterized by the following:

[**0124**] (1) In the present embodiment, in the vehicle having independently steerable four wheels, the electronic control unit **11** serves as the target vehicle behavioral-quantity calculation device and calculates the target yaw rate (target vehicle behavioral-quantity) in accordance with the vehicle speed V and the steering angle θ. The electronic control unit **11** serves as the vehicle-control target value calculation device and calculates the yaw rate difference $\Delta\gamma$ (vehicle-control target value) on the basis of the target yaw rate γ^* and the actual yaw rate γ. The electronic control unit **11** serves as estimation device and estimates the grip factors $\epsilon 1$ to $\epsilon 4$ of the individual wheels to the road surface. The electronic control unit **11** serves as the distribution-ratio-setting device and sets the distribution ratio for distribution of the vehicle-control target value among the actuators of the steering, brake, and drive systems in accordance with the estimated grip factors $\epsilon 1$ to $\epsilon 4$. The electronic control unit **11** serves as the control device and controls the actuators of the three systems in accordance with the respective vehicle-control target values allocated in the set distribution ratio; i.e., in accordance with the control instruction values At, Bt, and Ct (vehicle-control target values).

[**0125**] As result, in the embodiment, in the vehicle of a four-wheel, independent steering type, the actuators of the individual systems are driven and controlled in accordance with the tire conditions of the individual wheels; i.e., the grip factors $\epsilon 1$ to $\epsilon 4$ of the individual wheels, in such a manner that the lowest grip factor increases. Therefore, the travel stability of the vehicle can be improved as compared with the case where the grip factors of the individual wheels are not taken into consideration. In other words, since the actuators of the individual systems are controlled in an integrated manner while loads on the wheels are considered in a more optimal manner, the travel stability can be improved.

[**0126**] In particular, in the embodiment, the integrated control apparatus of the present invention is embodied in a four-wheel independent steering vehicle of a steer-by-wire type. Therefore, as compared with the case of an ordinary front-wheel steering vehicle, the respective grip factors of the four wheels can be accurately estimated, and the distribution of the vehicle-control target value of the steering system, the brake system, and the drive system can be controlled more optimally. Moreover, since changes in the grip factors of the wheels can be determined before the tires reach the grip limit (friction circle), robust and highly accurate estimation of the grip factors can be expected.

[**0127**] Moreover, as in the case of existing brake control independently performed for the individual wheels, the steering system can perform independent control for each wheel. Therefore, more fine optimal control can be performed in accordance with the vehicle behavior quantity, whereby the vehicle stability can be secured and enhanced in a wider range of situations.

[**0128**] (2) The drive system of the vehicle **1** of the present embodiment includes the drive force distribution unit **7** for distributing drive force to the front wheels (front right wheel FRW and front left wheel FLW) and the rear wheels (rear right wheel RRW and rear left wheel RLW); and the electronic control unit **11** controls the actuator (electromagnetic solenoid) of the drive force distribution unit **7**. As a result, in an embodiment, the above-mentioned action and effects can be attained through operation of controlling the distribution of drive force to the front wheels and the rear wheels in accordance with the tire conditions of the individual wheels; i.e., the grip factors $\epsilon 1$ to $\epsilon 4$.

[**0129**] Another embodiment of the present invention will next be described with reference to FIGS. **10** to **15**. Configurational features identical with those of the previous embodiment are denoted by common reference numerals, and repeated description thereof is omitted; and different features are mainly described. This embodiment differs from the previous embodiment only in the method of estimating the grip factor in the electronic control unit **11**. In other words, this embodiment estimates the grip factor ϵ while using the slip angle of the wheel as a wheel index. Notably, in this embodiment, the grip factor ϵ includes the grip factors $\epsilon 1$ to $\epsilon 4$.

[0130] **FIG. 10** is a block diagram of the grip factor calculation section **41**, which estimates the grip factor from the slip angle of the wheel and self-aligning torque. The torque detection device **M2**, the reaction torque detection device **M3**, the steering-angle detection device **M4**, the friction torque estimation device **M5**, and the self-aligning torque estimation device **M6** are similar to those of the previous embodiment. Reaction torque and friction torque are calculated, and self-aligning torque is estimated. The slip angle of the wheel is obtained on the basis of the steering angle θ, the actual yaw rate γ, the actual lateral acceleration Gy, and the vehicle speed V. Thus, as in the case of the previous embodiment, detection signals from the steering-angle detection device **M4**, the lateral acceleration detection device **M7**, and the yaw rate detection device **M8**, together with a detection signal from the vehicle speed detection device **M9***x*, are input to wheel slip estimation device **M9***y*, which serves as wheel index estimation device. In the present embodiment, the vehicle speed sensor serves as the vehicle speed detection device **M9***x*.

[0131] The steering-angle detection device **M4**, the lateral acceleration detection device **M7**, the yaw rate detection device **M8**, and the vehicle speed detection device **M9**×serve as the vehicle behavioral-quantity detection device for detecting the behavioral-quantity of the vehicle.

[0132] In the wheel slip estimation device **M9***y*, first, a body slip angular-speed dβ/dt is obtained on the basis of the actual yaw rate γ, the actual lateral acceleration Gy, and the vehicle speed V. The obtained body slip angular-speed dβ/dt is integrated, thereby yielding the vehicle-body slip angle β. On the basis of the vehicle-body slip angle β, the slip angle αf is calculated by use of the vehicle speed V, the steering angle θ, and vehicular specifications. Notably, the vehicle-body slip angle β can be estimated by use of a vehicle model instead of the integration method. Also, the vehicle-body slip angle β can be calculated by combined use of the integration method and the modeling method.

[0133] On the basis of the above-estimated self-aligning torque and slip angle af, the self-aligning torque gradient-at-origin estimation device **M10** identifies the gradient of self-aligning torque near the origin. On the basis of the obtained gradient and the slip angle, the reference self-aligning torque setting device **M11** sets a reference self-aligning torque. On the basis of the result of comparison between the reference self-aligning torque set by the reference self-aligning torque setting device **M11** and the self-aligning torque estimated by the self-aligning torque estimation device **M6**, the grip factor estimation device **M12** estimates the grip factor ϵ (including ϵ1 to ϵ4) of the wheel.

[0134] The above-mentioned estimation of the grip factor ϵ will be described in detail with reference to FIGS. **11** to **15**. As shown in **FIG. 11**, the relation of the side force Fyf and the self-aligning torque Tsa with the wheel slip angle (hereinafter called the "slip angle αf") exhibits a nonlinear characteristic in relation to the slip angle αf. Since the self-aligning torque Tsa is the product of the side force Fyf and the trail e (=en+ec), a self-aligning torque characteristic in the case of the wheel being in grip condition; i.e., the pneumatic trail en being in complete grip condition, is nonlinear as represented by Tsar in **FIG. 12**.

[0135] However, in the present embodiment, a self-aligning characteristic in complete grip condition is assumed to be linear. As shown in **FIG. 13**, a gradient K2 of the self-aligning torque Tsa in relation to the slip angle as measured in the vicinity of the origin is obtained, and a reference self-aligning torque characteristic (represented by Tsas in **FIG. 13**) is set. For example, when the slip angle is αf1, the reference self-aligning torque is calculated as Tsas1=K2·αf1. The grip factor ϵ is obtained as ϵ=Tsaa1/Tsas1=Tsaa1/(K2·αf1).

[0136] The method of **FIG. 13** for setting the reference self-aligning torque assumes the reference self-aligning torque characteristic to be linear. As a result, in a region where the slip angle α·f is large, an error associated with estimation of the grip factor becomes large, possibly resulting in impaired accuracy in estimation of the grip factor. Therefore, preferably, as shown in **FIG. 14**, at a predetermined slip angle or greater, the gradient of self-aligning torque is set to K3, whereby the nonlinear characteristic of the reference self-aligning torque is linearly approximated as represented by OMN in **FIG. 14**. In this case, preferably, the self-aligning torque gradient K3 is experimentally obtained and set beforehand, and, during running, the gradient K3 is identified and corrected. The point M is set on the basis of an inflextion point (point P) of the actual self-aligning torque. For example, the inflextion point P of the actual self-aligning torque is obtained. Then, a slip angle αp corresponding to the inflextion point P is obtained. A slip angle that is greater than the slip angle αp by a predetermined value is taken as αm. A point on the straight line of the gradient K3 that corresponds to the slip angle αm is set as the point M.

[0137] Furthermore, since the characteristic of the reference self-aligning torque in relation to the slip angle is influenced by friction coefficient μ of the road surface, as shown in **FIG. 15**, the reference self-aligning torque is set on the basis of the inflextion point P of the actual self-aligning torque Tsaa, whereby a highly accurate reference self-aligning torque characteristic can be set. For example, when the friction coefficient of the road surface lowers, the characteristic of the actual self-aligning torque Tsaa changes from representation by the solid line to representation by the broken line in **FIG. 15**. Specifically, when the friction coefficient μ of the road surface lowers, the inflextion point of the actual self-aligning torque Tsaa changes from the point P to a point P'. Therefore, the reference self-aligning torque characteristic (Tsat) must be changed from OMN to OM'N'. In this case, a point M' is set on the basis of the inflextion point P'; thus, even when the friction coefficient of the road surface changes, the reference self-aligning torque characteristic can be set while following a change of the friction coefficient of the road surface.

[0138] This embodiment can yield actions and effects similar to those of the previous embodiment described above.

[0139] Further embodiment of the present invention will next be described with reference to **FIG. 16**. The further embodiment has the same hardware configuration as that of the previous embodiments and differs from the other embodiment in the method of calculating grip factors in the grip factor calculation section **41**.

[0140] In previous embodiments, attention is paid to change in pneumatic trail of each wheel, the grip factor of each wheel is obtained on the basis of self-aligning torque.

The grip factor calculation section **41** of the present embodiment estimates the grip factor of each wheel, which represents the grip level of the wheel in the lateral direction (the grip factor in this case is represented by ϵm), on the basis of the allowance of side force with respect to friction of a road surface, in place of self-aligning torque.

[0141] According to a theoretical model (brush model), the relation between wheel side force Fyf and actual self-aligning torque Tsaa is represented by the following equations. That is, in the case where $\xi=1-\{Ks/(3\cdot\mu\cdot Fz)\}\cdot\lambda$,

$$\text{when } \xi>0,\ Fyf=\mu\cdot Fz\cdot(l-\xi^3); \tag{3}$$

$$\text{when } \xi\leqq 0,\ Fyf=\mu\cdot Fz; \tag{4}$$

$$\text{when } \xi>0,\ Tsaa=(l\cdot Ks/6)\cdot\lambda\cdot\xi^3); \tag{5}$$

$$\text{when } \xi\leqq 0,\ Tsaa=0. \tag{6}$$

[0142] Notably, Fz represents surface contact load; l represents the contact length of a contact surface; Ks represents a constant corresponding to tread stiffness; and λ represents lateral slip ($\lambda=\tan(\alpha f)$), where αf is a wheel slip angle.

[0143] Since the wheel slip angle αf is generally small in the region of $\xi>0$, λcan be treated as being equal to αf. As is apparent from Eq. (3), since the maximum side force is $\mu\cdot Fz$, a road-surface-friction utilization ratio η, which is the ratio to the maximum side force corresponding to the road surface friction coefficient μ, can be represented by $\eta=1-\xi^3$. Accordingly, ϵm ($=1-\eta$) represents a road-surface-friction allowance level. When ϵm is considered a grip factor of a wheel, $\epsilon m=\xi^3$. Accordingly, the above-described Eq. (5) can be represented as follows.

$$Tsaa=(l\cdot Ks/6)\cdot\alpha f\cdot\epsilon m \tag{7}$$

[0144] Eq. (7) represents that the actual self-aligning torque Tsaa is in proportional to the wheel slip angle αf and the grip factor ϵm. Thus, reference self-aligning torque, which is actual self-aligning torque Tsaa at the time when the grip factor $\epsilon m=1$ (the road-surface-friction utilization ratio is zero; i.e., the road-surface-friction allowance level is 1), is represented as follows.

$$Tsau=(l\cdot Ks/6)\cdot\alpha f \tag{8}$$

[0145] Accordingly, from Eqs. (7) and (8), the grip factor ϵm can be obtained as follows.

$$\epsilon m=Tsaa/Tsau \tag{9}$$

[0146] As is apparent from the fact that Eq. (9) does not include the road surface friction coefficient μ as a control parameter, the grip factor ϵm can be calculated without use of the road surface friction coefficient μ. In this case, the gradient K4 ($=l\cdot Ks/6$) of the reference self-aligning torque Tsau can be set by use of the above-mentioned brush model. Alternatively, the gradient can be obtained empirically. Moreover, detection accuracy can be improved through an operation of first setting an initial value; identifying, during travel, the gradient of self-aligning torque in the vicinity of the zero wheel slip angle; and correcting the gradient.

[0147] For example, in **FIG. 16**, when the wheel slip angle is $\alpha f2$, the reference self-aligning torque is calculated as $Tsau2=K4\cdot\alpha f2$. Then, the grip factor ϵm is obtained as $\epsilon m=Tsaa2/Tsau2=Tsaa2/(K4\cdot\alpha f2)$.

[0148] Thus, instead of the grip factor ϵ determined on the basis of the pneumatic trail of an embodiment, the grip factor ϵm determined on the basis of the road-surface-friction allowance level can be used.

[0149] Notably, the grip factor ϵ in the embodiments and the grip factor ϵm in the embodiments have the relation shown in **FIG. 17**. Accordingly, the electronic control unit **11** may be configured in such a manner that a map representing this relation is previously stored in ROM or the like, and the electronic control unit **11** obtains a grip factor ϵ and then convert it to a corresponding grip factor ϵm. Alternatively, the electronic control unit **11** may be configured to obtain a grip factor ϵm and then convert it to a corresponding grip factor ϵ.

[0150] Notably, the embodiments of the present invention may be modified as follows.

[0151] In the above-described embodiment, the integrated control apparatus of the present invention is embodied in a four-wheel independent steering vehicle of a steer-by-wire type. However, the integrated control apparatus may be embodied in a four-wheel independent steering vehicle of a non-steer-by-wire type.

[0152] In the above-described embodiment, the electronic control unit **11** serves as target vehicle behavioral-quantity calculation device so as to calculate a target yaw rate, and serves as vehicle-control target value calculation device so as to calculate a vehicle-control target value on the basis of the target yaw rate and the actual yaw rate γ, which is a vehicle behavioral-quantity. However, the present invention is not limited thereto. For example, the electronic control unit **11** may include, as target vehicle behavioral-quantity calculation device, device for calculating a target tire lateral force, which is a target vehicle behavioral-quantity, and device for calculating a target vehicle yaw moment, which is a target vehicle behavioral-quantity. Further, the electronic control unit **11** may serve as vehicle-control target value calculation device so as to calculate a vehicle-control target value on the basis of the difference between the target tire lateral force and a tire lateral force, which is a vehicle behavioral-quantity, as well as the target vehicle moment, and the actual vehicle yaw moment, which is a vehicle behavioral-quantity.

[0153] In the above-described embodiment, the actuator of the drive system is the actuator of the drive force distribution unit **7**. However, the actuator of the drive system is not limited thereto, and may be an actuator for changing the throttle opening of the engine EG.

[0154] In the above-described embodiment, three systems are controlled in an integrated manner. However, it may be the case that two systems are controlled in an integrated manner; e.g., the drive system and the brake system, the drive system and the steering system, and the steering system and the brake system.

[0155] Obviously, numerous modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims, the present invention may be practiced otherwise than as specifically described herein.

What is claimed is:

1. An integrated control apparatus for a vehicle comprising:

a vehicle behavioral-quantity detection device detecting a vehicle behavioral-quantity;

an operation quantity detection device detecting a quantity of driver's operation to a brake system, a drive system, and a steering system capable of independently steering individual wheels of the vehicle;

a target vehicle behavioral-quantity calculation device calculating a target vehicle behavioral-quantity in accordance with the detected vehicle behavioral-quantity and the detected operation quantity;

a vehicle-control target value calculation device calculating a vehicle-control target value on the basis of the target vehicle behavioral-quantity and the vehicle behavioral-quantity;

an estimation device for estimating grip factors of the individual wheels to road surface;

a distribution ratio setting device setting, in accordance with the grip factors of the individual wheels, a distribution ratio for distribution of the vehicle-control target value among respective actuators of at least two systems among the brake system, the drive system, and the steering system; and

a control device controlling the actuators of the at least two systems in accordance with the vehicle-control target value distributed among the actuators at the distribution ratio.

2. An integrated control apparatus for a vehicle according to claim 1, wherein the target vehicle behavioral-quantity calculation device calculates a target yaw rate, which serves as the target vehicle behavioral-quantity; and

the vehicle-control target value calculation device calculates the vehicle-control target value on the basis of the target yaw rate and an actual yaw rate, which serves as the vehicle behavioral-quantity.

3. An integrated control apparatus for a vehicle according to claim 1, wherein the drive system includes a drive force distribution device distributing drive force between front wheels and rear wheels; and the control device controls an actuator of the drive force distribution device.

4. An integrated control apparatus for a vehicle according to claim 1, wherein the estimation device estimates each of the grip factors on the basis of change in pneumatic trail of the corresponding wheel.

5. An integrated control apparatus for a vehicle according to claim 1, wherein the estimation device estimates each of the grip factors on the basis of a road surface friction allowance level of the corresponding wheel.

6. An integrated control apparatus for a vehicle according to claim 1, wherein the estimation device comprises:

a steering-force-index detection device detecting a steering force index including torque applied to the steering system including steering mechanisms for the individual wheels;

a self-aligning torque estimation device estimating a self-aligning torque produced by each wheel on the basis of the detected steering force index;

a wheel index estimation device estimating, on the basis of the vehicle behavioral-quantity detected by the vehicle behavioral-quantity detection device, at least one wheel index among wheel indexes including side force and slip angle of each wheel; and

a grip factor estimating device estimating the grip factor of each wheel on the basis of change in the self-aligning torque estimated by the self-aligning torque estimation device in relation to the wheel index estimated by the wheel index estimation device.

7. An integrated control apparatus for a vehicle according to claim 6, further comprising a reference self-aligning torque setting device for setting a reference self-aligning torque on the basis of the wheel index estimated by the wheel index estimation device and the self-aligning torque estimated by the self-aligning torque estimation device, wherein the grip factor estimating device estimates the grip factor of each wheel on the basis of results of comparison between the reference self-aligning torque set by the reference self-aligning torque setting device and the self-aligning torque estimated by the self-aligning torque estimation device.

8. An integrated control apparatus for a vehicle according to claim 7, wherein the reference self-aligning torque setting device sets a reference self-aligning torque characteristic which is approximated from the characteristic of the self-aligning torque estimated by the self-aligning torque estimation device in relation to the wheel index estimated by the wheel index estimation device, the reference self-aligning torque characteristic being defined as a straight line in a coordinate system and passing through the origin of the coordinate system, and sets the reference self-aligning torque on the basis of the reference self-aligning torque characteristic.

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